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ASSESSMENT OF AVIONICS TECHNOLOGY IN EUROPEAN AEROSPACE ORGANIZATIONS

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EXECUTIVE OVERVIEW

The following report provides a summary of the observations and recommendations made by a technical panel formed by the National Aeronautics and Space Administration (NASA). The panel, comprising prominent experts in the avionics field, was tasked to visit various organizations in Europe to assess the level of technology planned for use in manufactured civil avionics in the future.

1.1 PURPOSE

The primary purpose of the study was to assess avionic systems planned for implementation or already employed on civil aircraft and to evaluate

future research, development, and engineering (RD&E) programs addressing avionic systems and aircraft programs. The ultimate goal is to ensure that the technology addressed by NASA programs is commensurate with the needs of the aerospace industry at an international level.

The panel focused on specific technologies, including guidance and control systems, advanced cockpit displays, sensors and data networks, and fly-by-wire/fly-by-light systems. However, discussions the panel had with the European organizations were not limited to these topics.

The assessment panel was composed of the following members:

D.A. Martinec (Panel Leader)	Aeronautical Radio Inc. (ARINC)
Robert Baumbick	NASA Lewis
Ellis Hitt	Battelle
Prof. Cornelius Leondes	University of Washington
Monica Mayton	Wright Patterson AFB
Joseph Schwind	Airline Pilots Association (ALPA)
Joseph Traybar	Federal Aviation Administration (FAA)

Panel consultants and support persons were:

Alan Angleman	W.J. Schafer Associates
Charles Homolka	ARINC Research Corporation
Dr. Ramon DePaula	NASA Headquarters
Cary Spitzer	NASA Langley Research Center

The assessment panel's complete itinerary is shown below.

Date	Organization Visited/Place
June 14, 1991	Deutsche Airbus - Hamburg, Germany
June 17, 1991	Deutsche Forschungs-und Versuchsanstalt fur Luft-und Raumfahrt (DLR) - Braunschweig, Germany
June 17, 1991	Teldix GmbH - Heidelberg, Germany (DePaula and Angleman only)
June 18, 1991	Aerospatiale - Toulouse, France
June 19, 1991	Sextant Avionique - Paris, France
June 20, 1991	Office National D'Etudes et de Recherches Aerospatiale (ONERA) - Toulouse, France
June 24, 1991	GEC Avionics - Rochester Kent, U.K.
June 25, 1991	Smiths Industries - Cheltenham, U.K.
June 26, 1991	British Aerospace - Bristol, U.K.

1.2 BACKGROUND

The current and evolving avionics developments in Europe, as perceived by the NASA study panel, are provided in summary format in this section. A comparison of European and U.S. avionics developments is also given. This section also highlights the thrust in European countries to accelerate avionics technology development, which is rapidly changing the relationship of the United States with other countries in the area of aerospace, particularly avionics.

1.2.1 Summary of Current European Avionics RD&E

The focus of European avionics RD&E varies with the goals of the organizations. Broad-based companies such as airframe manufacturers tend to focus their RD&E on aircraft systems in general. Instrumentation companies, for example the avionics manufacturers, concentrate on their specific area of expertise within avionics. The RD&E at their facilities tends to be more specialized and more speculative. The research organiza-

tions gear their programs to a wide range of subjects and perform their investigations at a high technical level. The following subsections address each type of organization individually.

1.2.1.1 Airframe Manufacturers

Aerospatiale, Deutsch Airbus, and British Aerospace, as key members of the Airbus Consortium, work closely to integrate systems and optimize the airframe design. Aerospatiale is now working on the A330 and A340 aircraft. The physical airframe designs are essentially completed. The integration of the avionics into the airframe is also nearly completed. Since the avionics suite is very similar to that of the A320, no real technological changes are expected for these new aircraft. For the near-term future, Aerospatiale will continue to focus its work on implementation rather than research.

British Aerospace is involved in numerous development programs. Although some of their programs are oriented toward the A330 and A340

aircraft, others are directed toward future aircraft. These include the A350 and possibly a new supersonic transport (SST) aircraft.

A key activity at British Aerospace is the development of integrated modular avionics (IMA). Their approach to IMAs differs from Boeing's; the intended use of physically distributed/logically centralized computing subsystems promotes an increased level of standardization; however, it introduces many technical challenges that must be resolved. These challenges will be addressed with a systems view of avionics design and integration. Specific technical areas of focus include the introduction of voice recognition and "smart" components for built-in test (BIT) equipment.

1.2.1.2 Avionics Manufacturers

Much of the research and development of the avionics manufacturers is being directed at displays, flight control systems, and solid-state gyros.

GEC Avionics is working to enhance head-up displays (HUDs). They have already produced a holographic HUD and are attempting to improve its performance by an order of magnitude through computer aiding. Smiths Industries is also developing a holographic HUD. Sextant is striving to market their new head-level display (HLD). The HLD has been applied on the Airbus A320 glare-shield.

Sextant Avionique, which owns the international patent rights to liquid crystal displays (LCDs), is investing in RD&E on a matrix LCD. Although Sextant reported that progress is being made, the technology is not yet ready for full-scale production. Smiths Industries has also included funds in their avionics RD&E program to investigate matrix LCDs.

Both Sextant and GEC Avionics are working on a miniature solid-state gyro. Both companies have reported substantial progress.

GEC Avionics is an internationally recognized leader for fly-by-wire and fly-by-light systems. Boeing has selected them to design the fly-by-wire system for the B-777 aircraft.

Smiths Industries is concentrating on improvements to aircraft fuel system gauging. Both optical and ultrasonic techniques have been used in their experiments.

1.2.1.3 Research Laboratories

The NASA panel visited Deutsche Forschungs-und Versuchsanstalt fur Luft-und Raumfahrt (DLR) (Germany), Office National D'Etudes et de Recherches Aerospatiale (ONERA) (France), and Sowerby Research Center (U.K.). The panel concentrated primarily on more advanced technology for long-term aircraft applications. These labs investigate a wide range of aircraft and avionics technologies. Each laboratory's research efforts are summarized in the following paragraphs.

Much of DLR's studies is oriented toward systems with a significant impact on operations. DLR is studying an enhanced flight management system to improve aircraft operation efficiency through optimum use of altitude, airspeed, and route. An additional improvement to aircraft operation efficiency could result from their work on a laminar wing with active controls. DLR is also studying the use of fiber optics in "smart" structures, power supplies, and interferometers.

Recently, DLR initiated projects to determine methods for optimizing automatic flight control systems and other navigation-related avionic systems. The focus of the automatic flight control system effort is to develop the means for flight path

control based on direct inputs from air traffic control (ATC). More accurate aircraft position information is desired and is considered achievable through enhanced navigation sensor performance. The avionics flight evaluation system (AFES) was constructed to test the various navigation systems. On-ground navigation in the terminal area is also included as part of their work.

The ONERA labs address a wide range of technologies, including aerodynamics, energetics, materials, computer science, physics, structures, and fluids. Studies that influence avionics comprise a small portion of the ONERA activities. Much of ONERA's aircraft-related work is in the area of radar, specifically signature recognition and stealth for military aircraft. There is particular emphasis on construction techniques for radar absorption. In line with this effort is their experimentation with lasers. To optimize the aerodynamics of the A330 and A340 aircraft, ONERA performs modeling work and conducts wind tunnel tests.

The Sowerby Research Centre of British Aerospace also conducts research in numerous areas. These include information processing, lasers, materials, aerodynamics, vulnerability, and human factors. Work in advanced information processing is of particular interest to those in the avionics field. Sowerby is currently combining different types of sensor information and injecting it into a sophisticated information processor. Preliminary laboratory results have demonstrated the achievement of relatively high reliability in object identification and tracking. Sowerby Research Centre claims to be at the international forefront of this technology.

1.2.2 Future Directions in European Avionics RD&E

Future RD&E in Europe will follow two paths. First, researchers will continue to advance

technologies currently being investigated. For example, follow-on programs in fault-tolerant modular avionics, a data bus using fiber optics, and distributed radar will be established. These programs do not necessarily encompass high-risk technology.

Second, programs employing newly developing and essentially unproven technology will start. Examples of this type of RD&E program are 3-D displays, single-mode fiber sensing, active sound cancellation, and virtual systems. The enhancement of instrumentation and avionics will also be studied with the introduction of a single-pilot cockpit being the ultimate goal.

1.3 HISTORICAL PERSPECTIVE ON U.S. AND EUROPEAN AVIONICS

The United States has been recognized as the international leader in the aviation industry over the previous decades. A clear indication of this leadership is its very high export/import ratio of not only numerous models of aircraft but also of their supporting avionics systems. This high ratio has been maintained for all facets of the aviation industry, including general aviation as well as military and civil air transport.

This U.S. lead can be partly attributed to aggressive production schedules and marketing in an era of high demand in virtually all segments of aviation. However, the primary driving force behind the worldwide demand for U.S. aircraft is the technology employed in structural design and the electronic systems used within the airframe.

The air transport industry realized a major success with the introduction of the B-707 and the DC-8. An even more significant success came later with the B-727, B-737, and DC-9. These aircraft, with their advanced systems, were readily accepted by the international air transport community and

established the United States as the leader in aircraft design and manufacturing.

In the late 1960s, a new breed of commercial transport was introduced to accommodate the large demand for international air travel: the long-range, wide-body aircraft. Three major U.S. airframe manufacturers entered the marketplace with these aircraft: Boeing, Lockheed, and McDonnell-Douglas offered the B-747, L-1011, and DC-10, respectively. All three designs proliferated in the international market.

Although the growing demand for air travel was a main factor in the popularity of these large aircraft, the technology available at the time of their introduction significantly contributed to the viability of their unique designs and operational capabilities. The high-accuracy inertial navigation system, derived from technology developed in U.S. space and military programs, was a key ingredient in the long-range navigation capability required for these aircraft.

The Airbus A300, the European contribution to the wide-body aircraft market, began service in 1973 equipped with more advanced avionics than its predecessors. In 1984, the A300/600 version entered the market. Although the A300/600 was a derivation of the earlier airframe, much of the technology for the A310 was implemented in its production.

The next generation of aircraft with advanced avionics was introduced in the early 1980s. Boeing produced the B-757 and B-767 with mostly traditional airframe designs but with significant differences in the avionics. The use of software-controlled microprocessors was prevalent in the avionics suite. Information was transferred between systems through extensive use of digital buses as opposed to analog signals. Conventional instrumentation readouts in the cockpit were replaced by

high-resolution cathode ray tubes (CRTs). Flight management computers for optimization of flights were standard equipment, and laser-based inertial reference systems were common.

Nearly concurrent with the introduction of the Boeing aircraft, Airbus Industrie offered the air transport industry the A310. The technology used in the wide-body A310 was at an equivalent level to the Boeing aircraft, with most of the avionics being a product of European RD&E. This is not surprising since the flight control system on the B-737 was from GEC Avionics.

Although the fly-by-wire technology had been implemented on military aircraft in Europe and the United States, Airbus was the first to apply the technology to commercial aircraft. The Airbus A320 provided a new pilot-aircraft interface approach by using a side-stick controller to sense pilot directional inputs rather than the typical yoke controller approach used for other commercial transport aircraft. This fly-by-wire capability has defined the latest generation of commercial transport aircraft.

The Airbus A330 and A340 scheduled to be released in 1992-1993, will be larger but will incorporate much of the technology implemented on the A320.

The B-777, now in development, is scheduled for release in 1995. The B-777 will be the first commercial air transport plane manufactured in the United States to use a fly-by-wire system. Although much of the design is not yet completed, Boeing intends to use a high degree of centralized processing and modularized avionics to achieve significant size and weight reductions. Other advances in technology, such as flat panel displays (FPDs) in the cockpit, promise additional weight and size reductions. Fault tolerance of the avionic systems is also high on the priority list.

1.4 AVIONICS ASSESSMENT PANEL COMPARATIVE ANALYSIS

European technology in commercial avionics is very competitive with that of the United States. The United States must step up its research and development of commercial avionics in order to regain its leadership position in the world market.

In tactical military avionics, however, the United States is clearly dominant. This is the result of many years of significant research and development investments made in such areas as integrated electronic countermeasures and electronic counter-countermeasures (ECM/ECCM), integrated electro-optical countermeasures and electro-optical counter-countermeasures (EOCM/EOCCM), multi-function radars, antisubmarine warfare (ASW), and spread spectrum communications. However, due to the changing world picture, funding for continuing development of tactical aircraft avionics for military applications is likely to decline, and tactical avionics is likely to acquire a diminished significance in the highly competitive international economic arena.

1.4.1 Technology Criticality Level

Estimated criticality levels for avionics technology are given in Table 1.4-1. Three criticality levels are established, as indicated in the legend. These levels are intended to denote the importance of a given technology to the production and marketing of new commercial aircraft, whose primary customer is commercial airlines. In other words, criticality, as the term is used in this discussion, is not directly associated with flight safety, reliability, or any other engineering parameter. Instead, it denotes the extent to which advanced systems in the technological areas listed will enable aircraft manufacturers to develop aircraft that are perceived as a better buy than the overseas competition.

Thus, because airlines are profit-driven, technology criticality becomes a function of the ability to reduce aircraft life-cycle cost per passenger mile. Improved reliability, safety, etc. are therefore important to the extent that they reduce airline costs by reducing maintenance costs, minimizing losses from accidents, etc. Simply put, advanced technologies that cannot demonstrate any linkage to airline profitability are of little practical importance in the marketplace. Hence, there is little reason to include them in a program of limited resources that has as one of its important goals the improvement of U.S. competitiveness in avionics.

Together with the comparison rankings (Section 1.4.1) criticality levels can help identify how the United States can maximize the payoff of new avionics research and technology development efforts in the future and improve its overall competitive position in the international market.

1.4.2 Comparative Rankings

Table 1.4-1 delineates seven key areas in avionics technology that the panel members feel are crucial to near-term and long-term leadership in the avionics field. Refer to the legend for an explanation of the ranking codes included in the table. The data in Table 1.4-1 is based on the panel members' findings. Subsections 1.4.1.1 through 1.4.1.6 expand on the panel's comparative rankings for each specific technology.

1.4.2.1 Avionics System Architectures

The European community currently has avionics computer codes that will enable implementation of efficient architectures on their next generation of commercial and military aircraft. Overall, however, U.S. avionics computer capabilities appear to be competitive with those of Europe.

Table 1.4-1. Avionics Technology Comparative Analysis

Technology	Criticality Level	Comparative Ranking
Avionics System Architectures	C	2
Avionics Computers	C	3
Microprocessors	C	2
Memory Devices	C	2
Interface Devices	C	2
IC Technology	C	2
Fault-Tolerant System/Architecture	C	3
Flight Control Systems	I	4
Flight Computer Systems	I	4
Flight Control Sensors	LI	3
Flight Control Activators	LI	3
Fly-by-Wire Subsystems	LI	4
Fly-by-Light Subsystems*	C	3
Navigation and Communication Systems	I	3
Global Positioning Systems	C	3
Microwave Landing Systems	LI	3
Inertial Navigation Systems	C	2
Ring Laser Gyros	I	2
Fiber-Optic Gyros*	I	3
Hemispheric Resonance Gyros*	I	1
Miniature Solid-State Gyros*	I	4
Display Systems	C	3
Liquid Crystal Displays	C	4
Electro-Luminescent Displays	I	2
Light-Emitting Diode Displays	LI	3
Cathode Ray Tube Displays	LI	3
Monitoring, Instrumentation, and Interface Systems	I	3
Automated Design and Engineering Systems	I	3
CAD/CAE/CAM Systems	LI	4
Automated Design Software	I	2
Optoelectronics and Photonics	I	3
Training and Simulation Systems	LI	3
Legend * - Developmental technology 1 - Clear U.S. dominance 2 - U.S. leadership but not clear dominance 3 - European and U.S. technology competitive 4 - European leadership but not clear dominance 5 - Clear dominance in Europe C - Critical I - Important LI - Less Important		

In comparing device technology, the United States has a slight lead over Europe. Most European avionics manufacturers are using federated architectures interconnected by the ARINC 429 data bus and, to a lesser extent, the ARINC 629 data bus.

The comparative analysis rankings for avionics computers and fault-tolerant features in Table 1.4-1, are based on system architectural considerations rather than manufacturing or component technologies used in these systems.

1.4.2.2 Flight Control Systems

The European community has on-going programs to support the continued growth of flight control system technologies and architectures, as indicated by their plans to provide advanced flight control systems for the B-777. European avionics manufacturers are committed to conventional and fly-by-wire technology in current production aircraft, and they are quickly taking the leadership in fly-by-light systems.

1.4.2.3 Navigation Systems

U.S. avionics manufacturers are concentrating their gyro research efforts on fiber-optic and hemispheric resonance gyro development. Europe has chosen to invest in the research and development of fiber-optic gyros and miniature solid-state gyros. The technology for development of integrated inertial navigation systems (INSs) is being largely pursued in the United States. Although the Europeans understand the technology for integrated INS, they are not actively researching these systems.

1.4.2.4 Display Systems

Europe and the United States appear to be competitive in all areas of display technology except

for liquid crystal displays (LCDs) where the European manufacturers appear to have a slight edge. The European community has traditionally enjoyed a lead over the United States in this technology, particularly in tactical systems. They have led the way in integrated head-level/head-up displays (HL/ HUDs) as applied to tactical systems. Evidence of active LCD production and use is provided by Sextant Avionique's new LCD head-level display (HLD) and their manufacturing facility in Grenoble, France. The United States currently lacks this level of production and use.

Sextant Avionique apparently intends to continue their current level of involvement in LCD technology. They are actively seeking customers for their products worldwide, including customers in the United States. There is no indication that the United States will be able to catch up in LCD technology over the next few years.

In the area of electroluminescent displays (ELDs), the United States is currently leading Europe. It is likely that the United States will maintain that lead for the near future.

The use of light-emitting diode (LED) displays in aircraft avionics is rare. Neither the United States nor Europe is actively pursuing this technology for extensive avionics use now or in the future.

CRT displays have been the standard but are diminishing in importance with the advent of advanced technologies such as LCDs. Advanced technologies offer comparable or improved readability in a smaller package with reduced life-cycle costs. The capabilities of U.S. and European CRT manufacturers are comparable.

1.4.2.5 Automated Design and Software Engineering

Europe, in particular Airbus Industries, apparently excels in the technology of avionics software development for commercial aircraft. Airbus Industries has in place a very comprehensive avionics software systems development environment, including avionics software systems specification definition and achievement. A program for the development and utilization of computer-assisted software engineering (CASE) tools is in place and is continuing to increase in effectiveness. It is not clear that the United States currently matches this level of capability.

1.4.2.6 Optoelectronics and Photonics

The funding levels for all the optics programs are relatively small, and the status of European technology trails U.S. technology in the area of sensor systems qualified for the aircraft environment. In terms of overall level of effort in this technology, the NASA/Navy Fiber Optics Systems Integration (FOCSI) program is ahead of the European aircraft community. FOCSI is a design study and hardware development program initiated to build, environmentally test, and fly a representative set of passive optical sensors for flight and propulsion control of advanced jet aircraft with outputs of the optical sensors compared to the BOM (bill-of-materials) electrical sensor set. The U.S. and European efforts in fly-by-light programs for civil aircraft are much closer in terms of devel-

opment. Both European and U.S. companies are in the technology-evaluation phase. Issues, such as the effect of adverse environments on optoelectronic components, need to be resolved before the technology can be installed in any significant number of production aircraft. Optical data buses will probably be used initially, more commonly than complete optical sensor systems.

1.4.2.7 Training and Simulation Systems

Both the United States and Europe appear to be generally competitive in training and simulation systems technology. England is especially competitive, with France slightly behind. In France, Aerospatiale has a leading role in researching and developing simulation systems.

The United States has the potential to take a strong lead in the future of training and simulation systems technology. A new simulator system currently being proposed for development by the U.S. Air Force and/or NASA could put the United States in a definite leading position in this area. The proposed simulator system would consist of a circular track with a 200-foot radius. A large gondola that could be subjected to significant G-forces would be situated on this track. It would house a complete, six-degree-of-freedom simulator with visuals. If this project is adopted and fully developed, it will be a significant advancement in training and simulation systems technology.

MAJOR PROGRAM AREAS

This section of the report addresses technologies of special interest due to their potential impact on the future of avionics. General topics include avionics system architectures, flight controls, navigation and communications systems, display systems, and automated design and software engineering. Subsections focus on specific systems and technologies under development by the European avionics industry. Within each section, an overview of European research is followed by more detailed information on those specific programs for which it was available.

2.1 AVIONICS SYSTEM ARCHITECTURE

2.1.1 Overview

Nearly all European avionics manufacturers are concentrating on federated architectures interconnected with the ARINC 429 data bus and, to a lesser extent, the ARINC 629 data bus for commercial avionics. Target aircraft include not only the Airbus A340 and derivatives, but also U.S. aircraft such as the Boeing-777. Research is under way in a number of companies and government agencies to develop fiber-optic data buses, as well as fiber-optic interfaces to ARINC data buses.

European companies are continuing to rely on dedicated processors performing specific functions such as flight control, navigation, and display generation. The use of a rack or enclosure containing a multiprocessing backplane bus is the subject of limited research. Most processors being used by European avionics companies are procured from U.S. suppliers such as Intel and Motorola, though some companies are using the Inmos Transputer.

Many companies are beginning to move from 16-bit architectures to 32-bit architectures such as the Intel 80386. Memory is obtained primarily from Japanese and European sources.

Overall, the European avionics community has a number of well-thought-out programs in place and is continuing the development of automation and software. Their efforts appear to be adequately comprehensive.

2.1.2 Program Specifics

European avionics manufacturers are concentrating on federated architectures that achieve fault tolerance through the use of dissimilar computers executing dissimilar software with the outputs compared at intermediate stages. Dissimilar software is derived from a single set of software requirement specifications by independent teams of software engineers using different software development tools. The number of computers used is dependent on the flight criticality of the functions implemented in the computers and their software.

In the area of avionics processors, the European trends are strong and well-defined, as follows:

- More efficient and effective development efforts;
- More reliable systems through appropriate architectures, smart components (i.e., BIT), application-specific integrated circuits (ASIC), and other appropriate means; and
- Faster and more effective system maintenance.

Advances in very-large-scale integration (VLSI) technologies are proceeding on the inter-

national scene in accordance with fairly well-defined trends, as are advancements in architecture and standards. General technology trends in VLSI development include the following:

- Reduced manufacturing costs by incorporating architectures that reduce the amount of wiring required, improving testability in subsystem design to ease integration, and using standardized test equipment. This last item is viewed as particularly important.
- A strong thrust toward reduced maintenance costs through the use of smart components (i.e., those that incorporate BIT), improved fault-finding resolution, and deferred maintenance such as continuous system functioning until an optimum maintenance time and location are found.
- Triple-redundant systems for fly-by-wire flight control systems that use different computer architectures for each of the three computers.
- The use of application-specific integrated circuit components to improve system reliability by reducing component count.
- Partitioning of avionics processor functions and locations and promotion of hardware and software reusability to reduce development time and costs.

The DLR Institute for Flight Guidance (IFG) conducts research in three major fields:

- Optimum task sharing between humans and automated systems, including pilot/controller interactions, ergonomic design

of display and controller systems, and the limits of automation.

- Automatic control systems, including fault-tolerant systems, automatic flight path control, and computer-assisted air traffic control.
- Improved sensor systems, including navigation systems for enroute flight, approach, and landing.

The DLR IFG is developing a redundant fly-by-light helicopter yaw control system that uses a Versatile Multiplex Europa (VME) bus as the high-speed backplane bus. The VME bus interfaces with an ARINC 429 digital air data computer, radio altimeter, and Attitude and Heading Reference System (AHRS). Pilot inputs/outputs to and from actuators are transmitted via fiber-optic links. The system is triple-redundant with implemented inter-lane communications. The outputs of the three fiber-optic channels to the actuators are cross-strapped so that each of the two actuator systems receives three inputs which are converted to electrical signals and voted. The outputs of the two-channel actuation system are then summed to produce the actual command. The IFG is also working on a quadruplex system that operates on similar principles.

Separately, DLR is developing an image processor for scene correlation processing of imagery from sensors. This has the potential to provide a virtual picture in the visual band of imagery from radar and infrared sensors. A Kalman filter mix of laser and radar sensor data should be able to improve position accuracy.

At Toulouse, France, ONERA is researching massively parallel reconfigurable architectures using up to 500 processors. This could lead to reconfigur-

able architectures in which the processor interconnection topology evolves dynamically during the application. Processors could be optically interconnected using a liquid crystal valve as the space-light modulator.

British Aerospace's Control Technology Programme should ultimately generate several benefits over the life cycle of new aircraft. Greater hardware and software reusability and partitioning of systems by function and location should reduce development efforts. Reduced wiring, greater testability, and standardized test equipment will reduce manufacturing costs. Improved fault-finding capabilities will reduce maintenance costs.

The Control Technology Programme's integrated modular avionics concept is illustrated in Figures 2.1-1 and 2.1-2. In Phase I of this effort, system boundaries will be re-evaluated, candidate architectures will be defined, and a hazard analysis will be conducted. Prototype components will be assembled to construct a working-systems-level digital control laboratory. In Phase II, this laboratory will be used to conduct detailed evaluations of candidate architectures, conduct a mini-certification exercise, determine the potential cost benefit of integrated modular avionics, and propose a possible flight experiment program.

GEC Avionics is developing the flight control system architecture for the B-777. As illustrated in Figure 2.1-3, this system has three dissimilar lanes for each of three identical channels. Lanes A, B, and C in each channel use dissimilar hardware and software. The system also uses multiple voting planes. The software specification is common and all lanes use the same control laws. The N-version software is written by different GEC panels using different compilers and different higher-order languages. Although GEC Avionics has investigated

analytic redundancy, they are not currently using this technique.

GEC Avionics Flight Control Division has developed a fly-by-light system for Airship Industries' experimental dirigible, the SKYSHIP 600. Outputs from the flight control computers are converted into optical data signals and transmitted over fiber-optic cables to the control surface actuator drive unit, which converts the signals back into electrical signals that are then used to control the movement of the control surfaces.

Deutsche Airbus' Digital Flight Data Recording System (DFDRS) is a crash-protected, solid-state flight data recorder with an erasable programmable read-only memory (EPROM) and 17 MB of data storage. It records 414 parameters (numeric and discrete) and has a minimum recording capacity of 25 hours. Data is organized in four 128-word subframes to fulfill Federal Aviation Administration (FAA), Commercial Aeronautics Administration (CAA), and International Civil Aviation Organization (ICAO) requirements. Subframes of 64 words to feed old flight data recorders are possible by adequate pin coding. This system is loaded through a standard data unit on board the aircraft from a 3.5-inch diskette prepared on a personal computer. The diskette contains a database that specifies data to be recorded. The system has a 3.6-MB battery-powered, static random access memory (RAM). Future development will allow implementation of program changes via the ACARS link. The evolving on-board maintenance system (ARINC 624) combines the Centralized Maintenance Computer (CMC) and the ACARS.

The Deutsche Airbus Aircraft Condition Monitoring System (ACMS), shown in Figure 2.1-4, includes 3,300 ARINC 429 data words for 12,700 possible parameters, both numeric and discrete. The system has continuous monitoring of 312

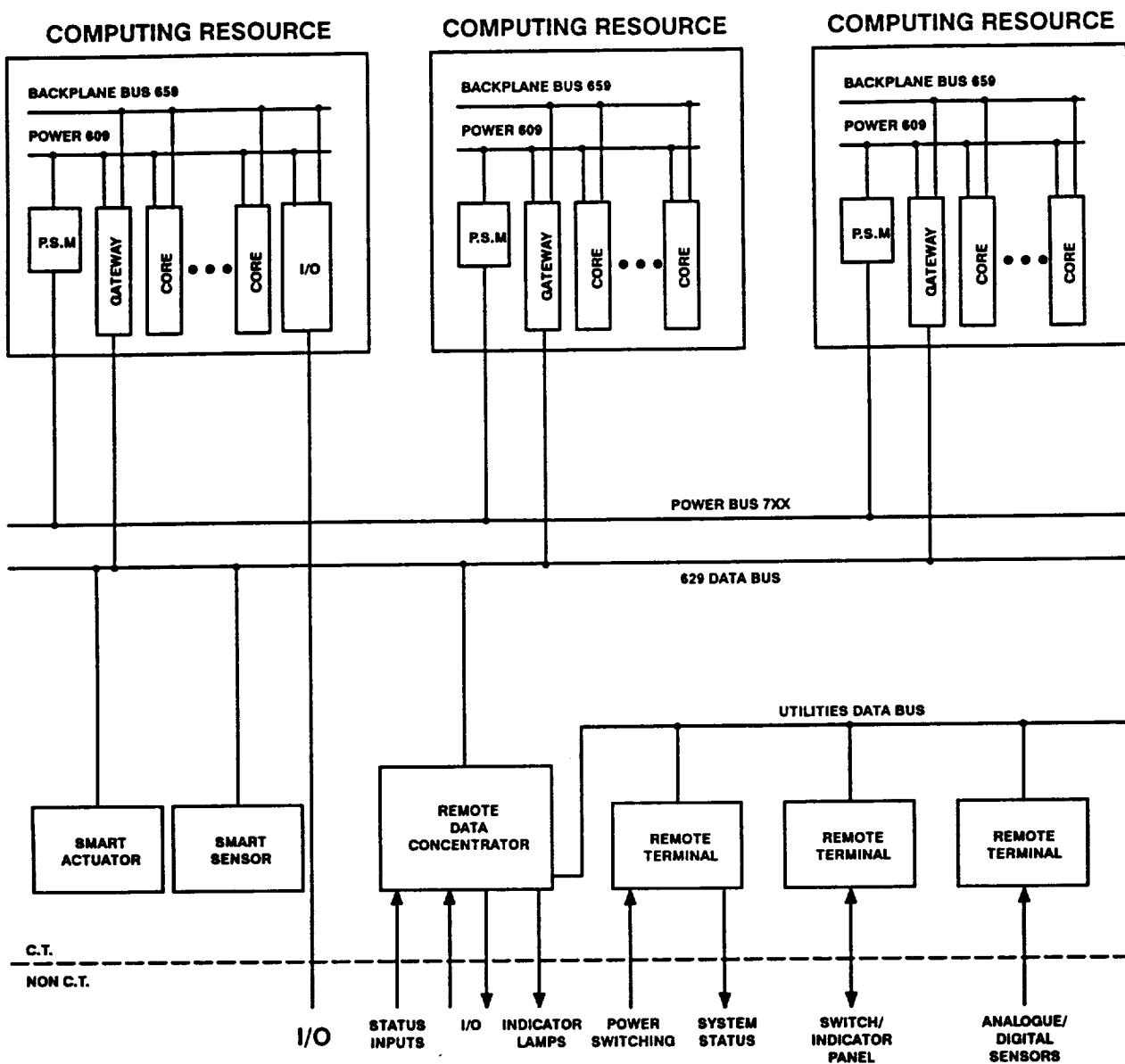


Figure 2.1-1. Control Technology Programme Integrated Modular Avionics (IMA) Concept

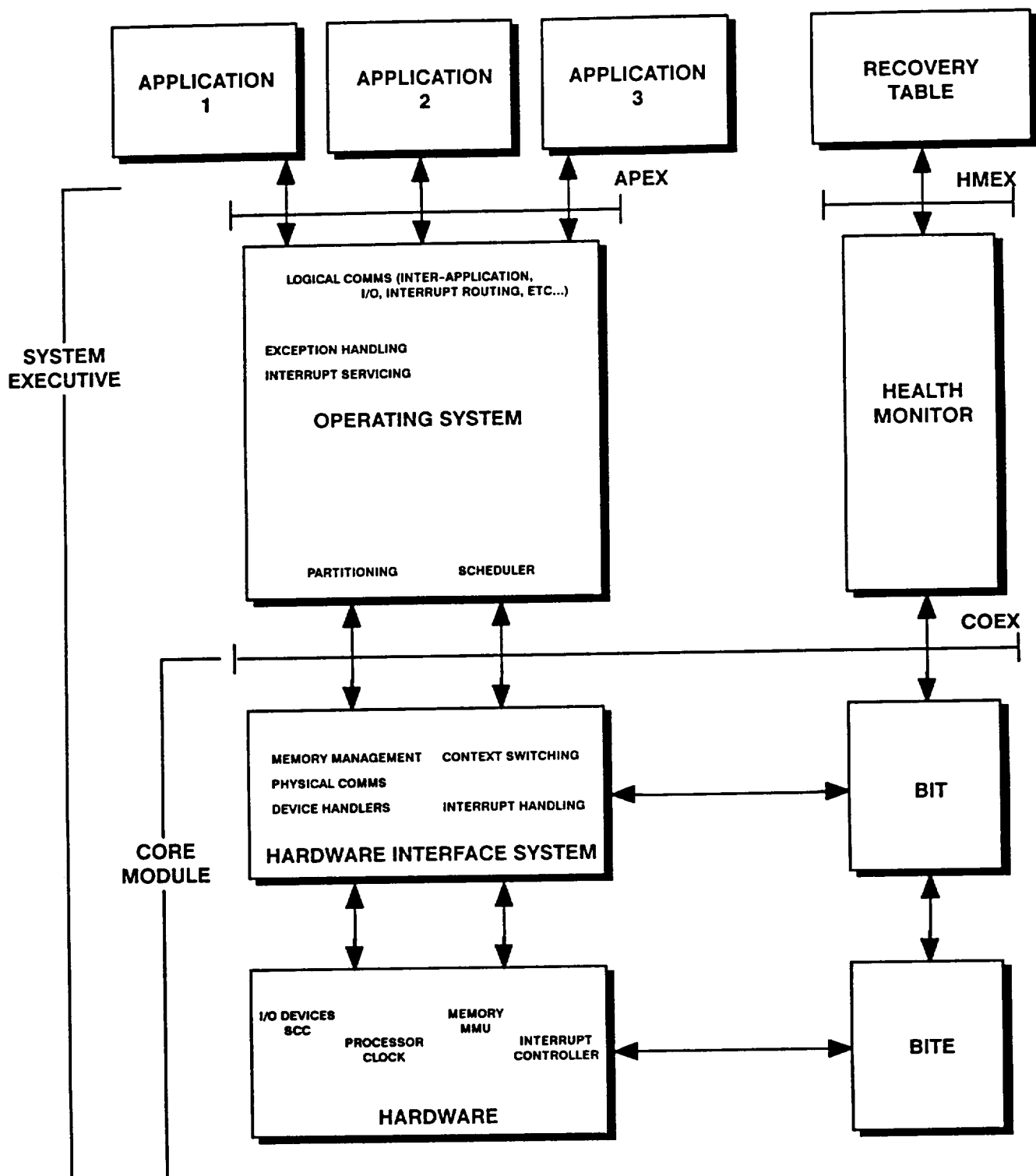


Figure 2.1-2. Control Technology Programme Software Architecture

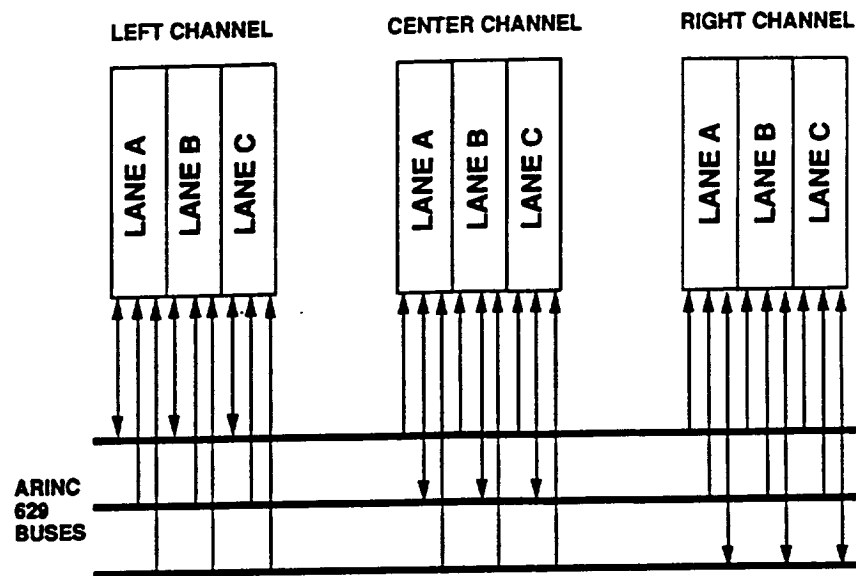


Figure 2.1-3. GEC Avionics 777 PFCS System Architecture

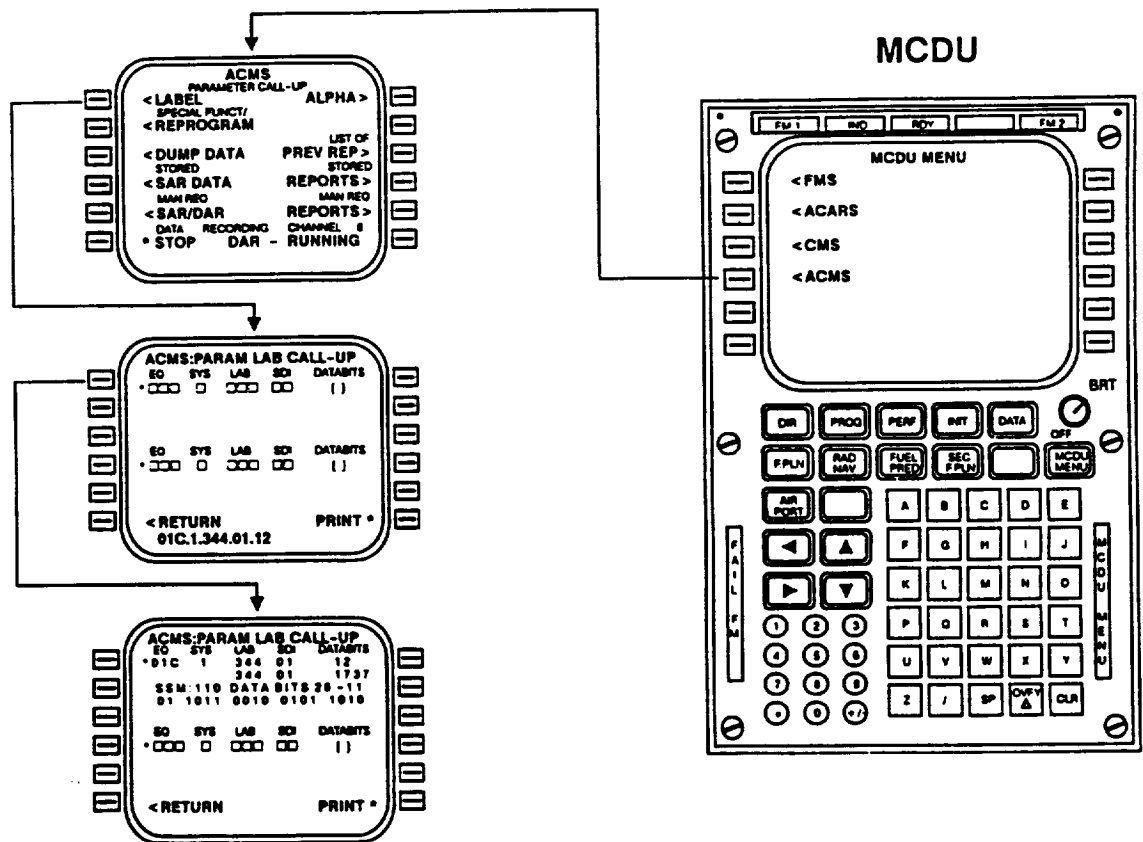


Figure 2.1-4. ACMS Operation

numeric and 288 discrete parameters with data compression for storage in a solid-state mass memory. It can generate 18 standard print reports for various purposes using both free programmable Digital ACMS Recorder (DAR) and Smart ACMS Recorder (SAR) data. Boeing has each of its customers define ACMS functions, whereas Airbus provides only standard functions. A block diagram of the DFDRS, ACMS, Common Modular Simulator (CMS), and ACARS is illustrated in Figure 2.1-5.

Other programs of interest at Deutsche Airbus include the effort to replace fly-by-wire (FBW) electrical signal transmission with optical fly-by-light (FBL) systems. Optical signal transmission will allow the use of a closely meshed network of optical wave guides.

Aerospatiale is also working on FBL flight control systems that use a network with a star-layered topology, as shown in Figure 2.1-6. In this arrangement, every receiver has the same optical distance from the transmitters. Aerospatiale's design features four branches with six layers per branch. Work is still under way on the protocol for this architecture. Aerospatiale is also investigating the use of an optical backplane to connect electronic units with interface units through networks to optical/electrical sensors as well as optical incident sensors, optical position sensors, and optical temperature sensors.

2.2 FLIGHT CONTROLS

Over the last several decades, the definition of flight control systems has changed significantly. In the distant past, conventional flight controls used aeromechanical designs in which the pilot's controller was directly connected to the control surfaces. These are now giving way to FBW flight control systems in which the pilot's controller is connected

only to electrical transducers and force from the pilot's stick is not placed directly on the control surface. FBW systems are themselves a stepping stone to the latest developments in flight control technology, FBL systems. FBL systems consist of optical interconnects that simplify data bus communications and decrease complex wiring interconnections. Recent technological advances in all three flight control systems are discussed in this section.

2.2.1 Overview

The general characteristics of conventional versus FBW flight controls has changed as technology in this area has improved. In the 1950s, conventional flight controls were those designs in which the pilot's stick was connected directly to the control surfaces via linkages, cables, and push-pull tubes. The aerodynamic surface forces and hinge moments were sensed by the pilot through the controller.

Later, when boosted flight control systems were introduced, certain conventional systems began to be characterized as fully powered and irreversible flight controls. These flight control systems usually incorporated hydraulic or electric power/torque mechanisms near the control surface that moved them in relation to the pilot's controller displacement commands. Since the pilot's controller was connected only to an electrical transducer or hydraulic power pilot-valve of the power-boost surface actuator, the pilot felt no inherent force and displacement feedback through the controller. Therefore, these irreversible flight control systems typically included some type of variable controller-load-feel-system comprising such components as force springs, centering springs, detents, stick trimmers, stick dampers, and Q-force bellows. These devices provided the pilot with appropriate force and displacement cues, gradients, and dynamics at the controller in the cockpit.

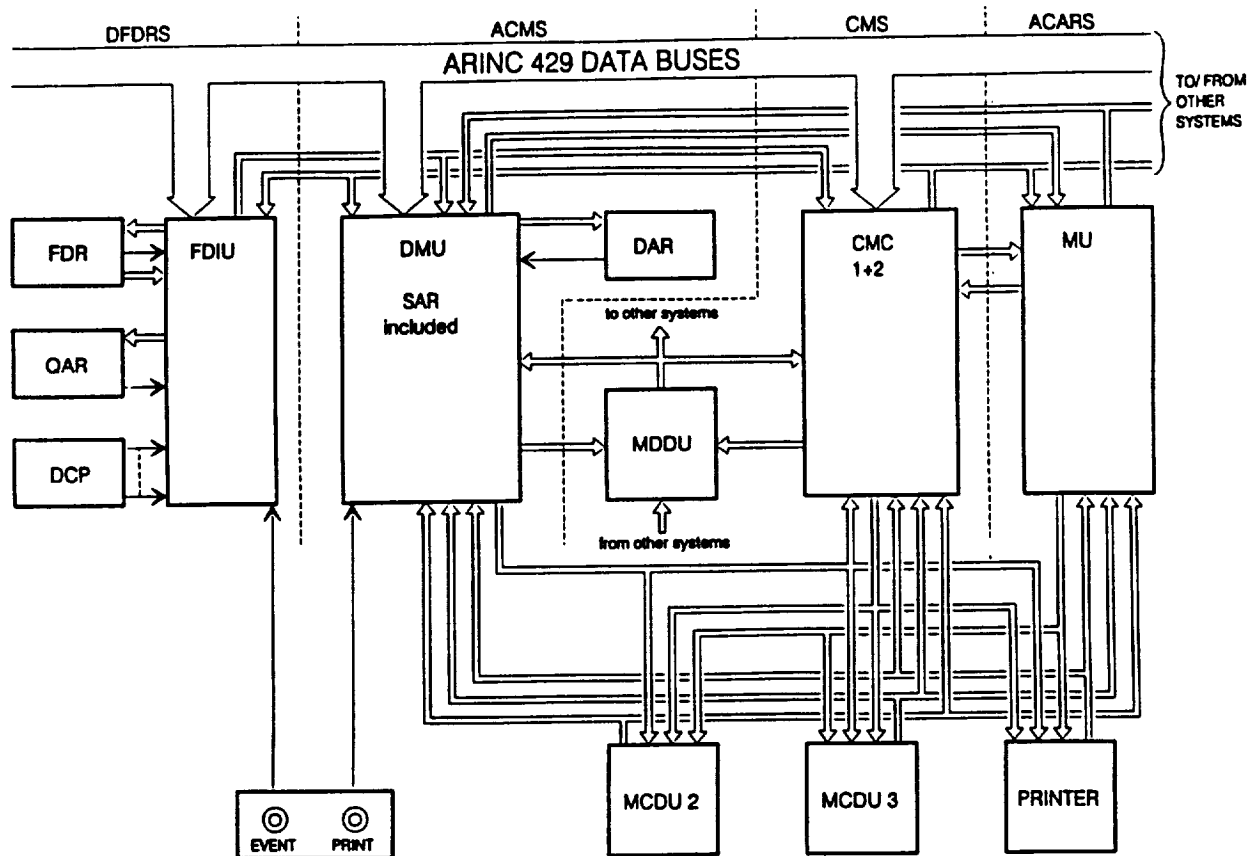


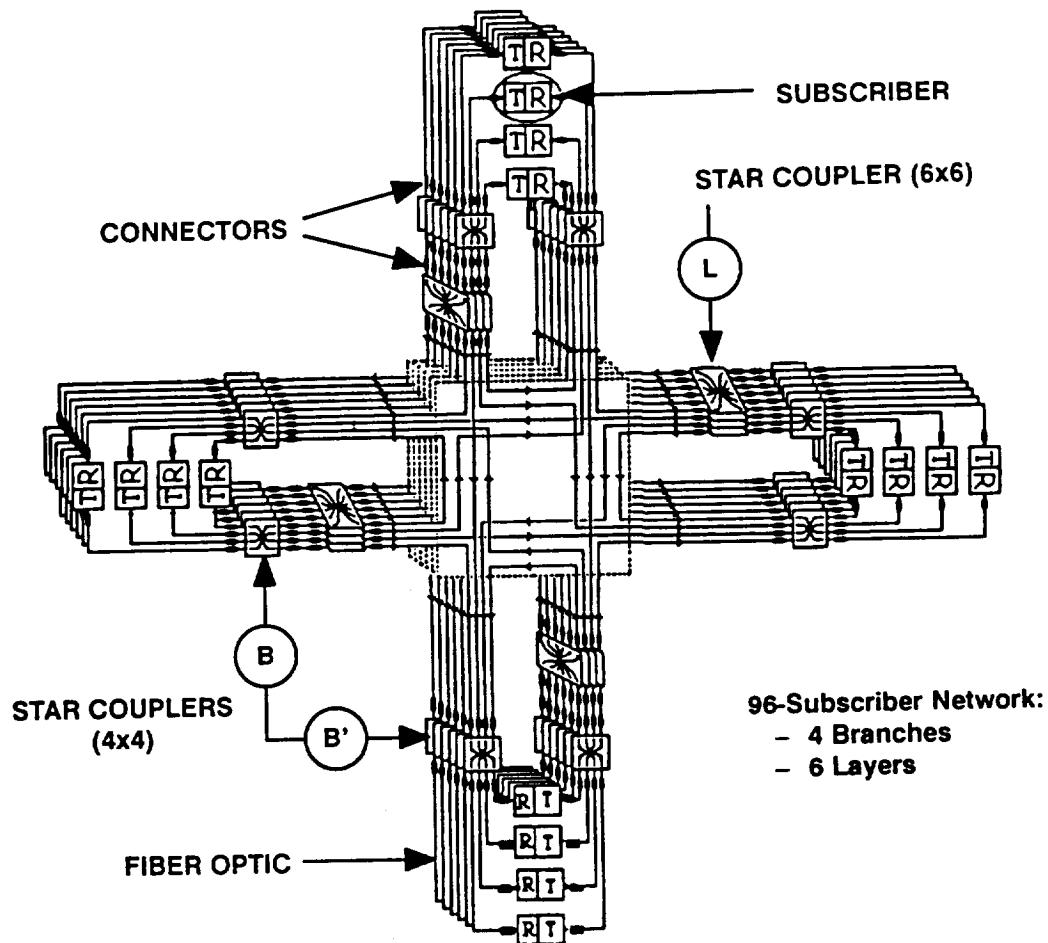
Figure 2.1-5. A330/A340 ARMS Principal Block Diagram

Excessive control sensitivity at higher airspeeds can present the pilot with an unacceptably low controller stick-force-per-G gradient characteristic. This condition makes it easy for the pilot to exceed the flight envelope of the aircraft and thus jeopardize the structural integrity of the vehicle. Frequent use was made of extensible links or floating fulcrums in the controller/control-system push-pull tubes to enable the pilot to provide some brute-strength muscle force directly to the control surface hinges, thereby bypassing the power actuators in the event of their failure. However, some fully powered control system architectures are, in fact, coupled entirely by hydraulics. The loss of hydraulic fluid and pressure results in loss of control surface action. Therefore, fully powered control systems

contain redundant systems such as hydraulic pumps, accumulators, tubing, reservoirs, hydraulic fuses, and priority sensors.

Nevertheless, these conventional, redundant, hydraulic-based systems have failed to various degrees, resulting in several fatal airliner accidents. One of the reasons for their failure is that they contain certain fragile hydraulic components. The hydraulic components must, of necessity, be routed and/or concentrated in locations such as the aft fuselage or forward empennage. These locations make the components vulnerable to the major stresses of center-engine (fuselage) fan/turbine rotor bursts, and aft fuselage pressure bulkhead failure. Major failures in hydraulic redundant

ARCHITECTURE FOR A TYPICAL 96-SUBSCRIBER APPLICATION



ADVANTAGES

- Potential for large number of subscribers
- Use of conventional and reliable components and all types of fiber (Silica/Silica, HCS, POF)
- Preferential modular structure
- Important growth potential
- Allows internal segregated routes
- High global reliability expected
- Well-adapted to an aircraft scheme

DRAWBACKS

- Great number of optical cords
- Wrap around time evaluation
- Protocol 629 application to be examined

Figure 2.1-6. Fly-By-Light Control System with its Network Based on a Star-Layered Topology

systems have resulted in catastrophic loss of aircraft control causing fatal crashes. Major structural loss of flight control surfaces, such as elevators and stabilizers, with no auxiliary or reconfigurable pitch control option to promptly call upon differential wing spoilers or collective ailerons for emergency pitch control, has also resulted in complete loss of control and subsequent accidents.

Fly-by-wire (FBW) systems are replacing hydraulic systems in many applications. The definition of fly-by-wire has been extensively covered over the years. Where digital technology is employed, the term fly-by-wire refers to advanced flight control systems and new commercial aircraft that incorporate redundant, full-authority, high-gain, digital design features, including computers, processors and bus technologies, in-situ fluid devices, and novel controllers, among others. FBW implies that the primary control is based on redundant, computer-oriented flight control systems, with conventional control architectures and hardware being relegated to minor or backup roles or, in certain designs, being completely absent from the aircraft.

For the purposes of this review, a general grouping of airliners with conventional control systems might include: the DC-9, DC-10, B-727, B-737, B-747, B-757, B-767, MD-11, A300, A310, and L1011. The MD-11 can have some optional digital stick-steering control and an attitude-hold function in pitch; the 747-400 has a digital engine/power control system and an advanced digital FMS; and the B-767, B-737, and B-747 may have some digital components to control spoilers; however, the fundamental flight control surface architectures are conventional.

Civil aircraft (current or projected) classed as non-conventional (FBW) might include: the Concorde (analog), A320, A321, A340, MD-12, and B-777. In comparing conventional flight control

systems between the U.S. and European sectors, it appears that there is little difference in the use of architectures for conventional control system technologies.

The key issues of conventional and FBW control systems pertinent to U.S.-versus-European technology fall into these general categories:

- Research and Development Levels,
- Simulation and Flight-Test Techniques,
- Certification Assessment,
- Safety Compliance,
- Cost-Effectiveness/Affordability.

The panel perceived from this tour that European companies are also "getting their feet wet" in the area of fly-by-light technology. Some of the apparent difficulties with this technology when applied to aircraft systems are:

- No guarantee that system optical power budgets will be adequate over system lifetimes.
- Difficulty of using optical techniques for fault location in the connectors and fibers because of the relatively short distances involved, which is making it difficult to provide BIT capabilities.
- Production skills required.
- Difficulty with installation techniques for supporting the optical fiber harnesses without affecting the optical integrity of the system.

-
- Maintenance problems due to environmental effects on the integrity of the components.
 - Availability of space for the sensors.

A number of European companies have undertaken research on using optics technology for control and health monitoring of flight and propulsion systems, communication, passive optical sensors for measurements, and photonics for optical computing. Although no one has optical systems in production aircraft, a number of companies visited are engaged in research in the areas of optical sensors, photonics, and optoelectronics. At this time, the effort is relatively low-level.

The main stumbling blocks in transitioning the technology to production systems are the lack of credible data to substantiate the reliability of the technology in the aircraft environment, problems with production techniques, and the integrity of fibers and other components in a relatively robust maintenance environment. A number of demonstration programs have been completed, including fiber-optic datalink installations in helicopters and large commercial aircraft. The primary interest in optics, at least for the present, concerns its potential advantages for flight control and data bus architectures relative to conventional systems in terms of:

- High certification costs,
- Complex wiring interconnections,
- Weight of harnesses,
- Susceptibility of wire systems to electromagnetic interference.

An additional reason given by one company was the ability to use dissimilar technologies (optical and electrical) for improving reliability.

2.2.2 Program Specifics

Only a few companies and research centers provided extensive direct information on FBW flight control technology and general control systems. Aerospatiale's Avions Division in Toulouse, France, reviewed advanced cockpit and operational systems for Airbus Industries' future aircraft (beyond A330 and A340). Airbus Industries favors the use of side-stick controllers (non-backdriven) and ARINC 429 buses, at least for the near-term. Pitch control laws will still be based on so-called C-star (C*) foundations, essentially a rate command characteristic in flight. Work on wind shear protection now focuses mostly on detection and avoidance, but in the future, additional options will be investigated. New aircraft will continue to provide some "floor" protection (e.g., stall, angle-of-attack) in the event of a shear encounter. Flight controller roll inputs will still essentially command roll rate. Spoilers will be used for flutter protection but will need great capabilities (rates of 200 deg/sec) and a very large bandwidth.

For the following discussion, the A320 is used as the European FBW base aircraft. The A320 uses rate-command/attitude-hold flight control pitch response for most of the flight envelope except for the landing flare. For the landing flare, the A320 transitions more to an attitude response characteristic. Airbus Industries terms this a "C**" or a "C* derivative" control law (Figures 2.2-1 and 2.2-2). Note that the C* nomenclature refers to old, and perhaps obsolete, handling qualities criteria that consist of envelopes defined by a combination of pitch-rate and normal acceleration feedback. In some cases, these envelopes have been found to be a poor way to identify good/bad

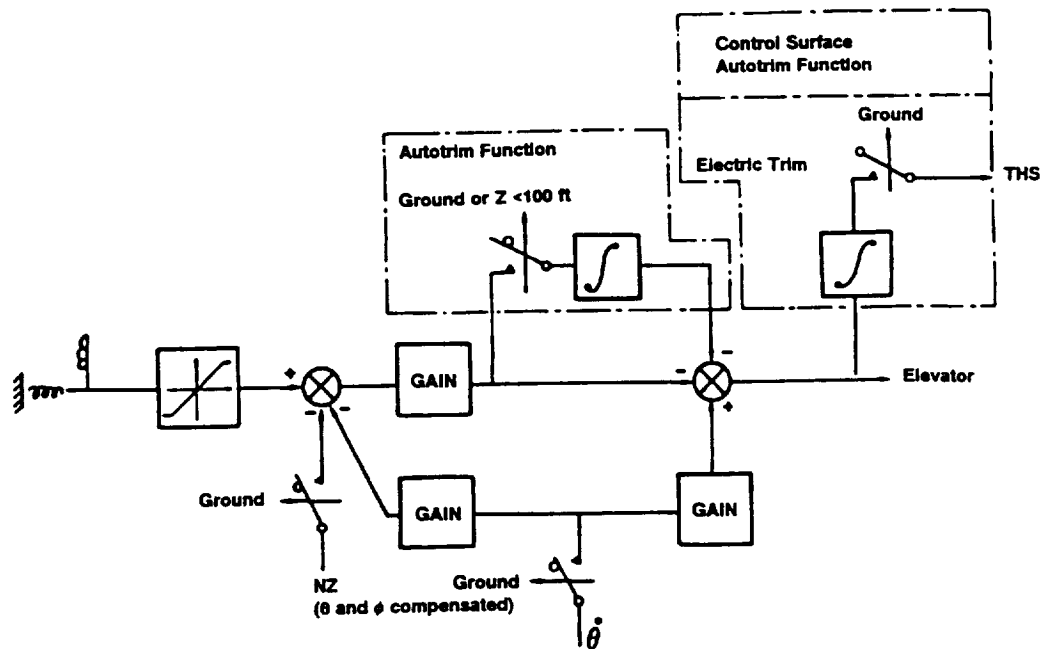


Figure 2.2-1. A320 C* Law Description

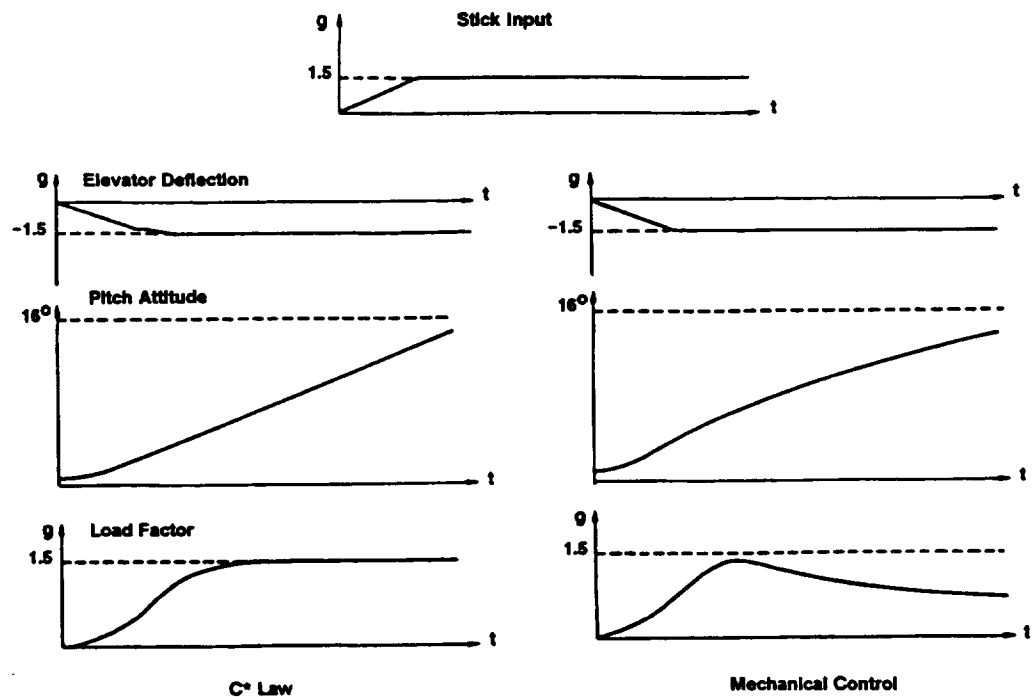


Figure 2.2-2. A320 C* Law Dynamic Characteristics

handling qualities and have been generally abandoned by many as handling qualities criteria.

It appears that since the A320 pitch axis control laws are based on pitch-rate and acceleration feedbacks, the A320's control system and law was dubbed a C* even though there may not be any connection with the old C* handling qualities envelopes. However, from the panel's visits in Europe, it seems that the designation C* (or C* derivative) is still attached to the Airbus Industries' FBW aircraft. At least one U.S. builder is investigating a modified C* response with airspeed and pitch-rate feedback to provide an aircraft pitch response closer to that of the older "pilot-learned" response patterns of more conventional systems. If high enough airspeed feedback gains are used, this would change the C* and rate command/attitude hold response to the more conventional response. However, this type of feedback could make the aircraft excessively responsive to gusts and atmospheric turbulence.

Some differences in philosophy between Airbus Industries and certain U.S. companies related to envelope limiting and envelope protection are present in flight systems technology development. The envelope limiting philosophy infers that the pilot cannot exceed a specified value of a flight boundary such as the "g" normal acceleration limits of the aircraft flight envelope. Envelope protection infers that the pilot is allowed to exceed the defined envelope by applying additional controller input. At this time, U.S. manufacturers favor the envelope protection philosophy whereas Airbus Industries favors the envelope limiting view. Thus Airbus Industries continues to use and defend it for future designs. Most DFBW systems employ either limiting or protection on vital quantities/characteristics such as angle-of-attack (stall), airspeed/mach number (overspeed conditions), and normal acceleration (positive and negative normal acceleration).

GEC Avionics offered the most information concerning their ongoing FBW technology developments. The Flight Controls Division at GEC Avionics has designed and implemented the Slat/Flap Control Computer (SFCC) on the FBW system for the Airbus A320. The Slat and Flap Control System for the Airbus family of aircraft is a digitally implemented electronic FBW control system with no mechanical reversion between the cockpit control lever and the hydraulic actuator. The FBW implementation provides:

- Weight savings due to the incorporation of protection features within the electronics,
- Accurate repeatability of surface position,
- Improved maintainability (lower-life cycle costs), and
- Greater flexibility for modification.

The slat/flap control computer forms part of a high-integrity FBW control system for the Airbus A320. The system uses established microprocessor technology coupled with the principle of dual-monitored architecture and dissimilar computing. The system provides in-flight signaling of the power control units (PCUs) to drive the slat/flap control surfaces in response to position commands. The system protects against inadvertent flap retraction at low speed and flap extension at high speed by comparing airspeed with limits set in the software. The system architecture combines high integrity with high availability.

Aerospatiale chose a FBW implementation approach for the A320 which meets safety requirements by using the following system components:

- Three identical spoiler and elevator computers (SECs), (Aerospatiale);

-
-
- Two identical elevator and aileron computers (ELACs), (Thomson-CSF);
 - Three identical air data and inertial reference systems (ADIRS) with separate sensors, (Honeywell);
 - Two identical flight augmentation computers (FACs), (Sfena);
 - Three separate hydraulic channels; and
 - Two separate main electrical power supplies and three backups.

The spoilers electronic control unit (SECU), also developed at the Flight Controls Division of GEC Avionics, forms part of a FBW control system for the Canadair Regional Jet. The system uses the same established microprocessor technology as the slat/flap control computer. In response to pilot commands, the system provides in-flight FBW signaling of the electrohydraulic actuators that drive the spoiler panels. Four pairs of spoiler panels, each pair comprising an inboard and outboard surface, are fitted and configured as multi-function and ground spoilers on either side of the aircraft. The spoilers are controlled individually by the SECU to provide:

- Conventional drag enhancement on the landing approach,
- Proportional lift dumping,
- Automatic deployment of the ground spoilers on touchdown, and
- Roll assistance to the mechanically signaled ailerons over the complete flight envelope.

GEC Avionics Flight Controls Division has developed and implemented the B-747 Full Flight Regime Auto-Throttle System (FFRATS), which is an analogue implementation of a complex control law that optimizes speed control and throttle activity over the entire flight range of the aircraft. The system responds to aircraft configuration changes, engine reference changes, flight path changes, and gust disturbances with smooth movement of the throttle levers, thus providing improved fuel economy, reduced pilot workload, and enhanced engine life.

FFRATS uses analogue computation, solid-state mode-switching, and digital BIT, all contained in a 1/2-ATR box. The BIT test capability provides a reliable and comprehensive fault indication. Life-cycle costs are reduced by the use of proven technology. A mode-select panel, mounted on the flight deck, provides the interface between pilot and system, indicating operational mode and system status. The three primary control modes are Speed Select, Mach Hold, and engine-pressure ratio (EPR) (or N_1). These control modes provide automatic control of speed or control of all four engines simultaneously, to an EPR limit value. The sub-modes consist of Minimum Speed, Flap Speed Limit, and EPR and provide protection features in each of the primary modes. The system can be configured for a variety of engine types and airframe variants.

GEC Avionics' Flight Controls Division has more than 30 years experience in hydraulic servo valve and actuator development. Various actuator programs have been undertaken, most of which are directed toward the high integrity and availability requirements of FBW applications and, more recently, toward FBL applications. The Hydraulics Laboratory and Production Facility (HLPF) is a completely self-contained area with its own environmental control systems. The development laboratory is completely equipped with modern control

equipment and can support a wide range of hydraulic, electrohydraulic and optohydraulic equipment. High standards of control and instrumentation are provided.

The Hydraulic Electric Generator (HEG), developed at HLPF, generates electrical power from the hydraulic supply in close proximity to the surface actuator to enhance the isolation between the various parts of the aircraft. It is currently offered as a back-up system to provide emergency power in the case of a loss of electrical power on the aircraft.

Fault-tolerant avionics is a new concept in the avionics industry, offering improved reliability and availability with an emphasis on scheduled, rather than unscheduled, maintenance. Fault-tolerant avionics will allow an avionics system to continue to operate for a considerable period of time after absorbing a succession of faults. Such faults will be transparent to system operation, although they will be monitored. Thus, fault-tolerant avionics will reduce the need for unscheduled corrective maintenance with consequent improvements in availability.

GEC Avionics has developed such a system by applying secondary redundancy within each of three individual units. These are arranged in a conventional triple-parallel-redundant configuration thus providing the accepted system integrity for a flight-critical system. Within each unit, three individual parallel-redundant computing chains are subdivided into three serial elements comprising an input link containing 12-bit analog-to-digital (A-D) conversion and discrete functions, a 32-bit high-speed microprocessor link and an output link capable of interfacing with ARINC 429, ARINC 629, or MIL-STD-1553B bus systems. These are then interconnected via serial communication interfaces to provide a matrix of elements to greatly increase the number of possible throughput paths. This matrix

can tolerate element faults until just one of each different serial element remains functional to provide the complete computational chain. A fault-tolerant avionics system can provide improved system reliability and, coupled with routine monitoring of equipment degradation, the elimination of unscheduled maintenance and a reduction in spare holdings. This powerful combination results in significant reductions in long-term cost of ownership.

GEC Avionics Flight Controls Division will also produce the Primary Flight Computer System (PFCS) for the Boeing Commercial Airplane Group, which will be central to the FBW system for the B-777. The aim of this effort is to provide a system with the integrity and reliability needed to satisfy the most stringent requirements put forth by Boeing.

Inputs from the pilot's control stick and rudder pedals are passed to the actuator control electronics (ACE) where they are digitized and sent on to the triplex ARINC 629 flight control data bus. Each primary flight computer (PFC) receives pilot commands from the data bus as well as aircraft motion information from air data and inertial sensors. Control laws within each PFC calculate the optimum actuator commands, based on pilot inputs and aircraft motion, to give safe and smooth control. These actuator commands are sent to the data bus, with each PFC transmitting to only one of the three data buses and hence to the ACE. Each ACE controls a number of actuators to move the primary and secondary control surfaces and to operate the backdrive and feel system to the pilot's controls. Each PFC has three hardware lanes in each box to provide triplicate secondary redundancy. This allows a PFC to continue operating after one failure and to fail safe after a second failure. Since there are three PFCs, unit replacement after failure is not an immediate concern and can usually be delayed until the next scheduled maintenance stop.

High reliability is achieved in the hardware design through extensive use of application-specific integrated circuits (ASICs) which considerably reduce component counts. Each box is designed to have immunity to the very demanding high-intensity radiation fields (HIRFs) specified for commercial FBW systems. GEC Avionics' extensive experience in shielding and protecting electronics used in FBW applications led to a box design that achieves this and also avoids the need for forced air cooling. Three different 32-bit microprocessors are used within the PFCs, each programmed in a different higher-order language to provide a high degree of protection against residual software errors. The 32-bit microprocessors provide adequate processing power.

At British Aerospace Commercial Aircraft Division, it was mentioned that work was being done in the area of gust load alleviation (GLA). The results of this work promise a 7% to 8% reduction in wing structural weight and a wing root bending reduction on the order of 15% (on the A320). The requirements for fast-moving surfaces (300 deg/sec outboard spoilers and ailerons) and the need for installation of hydraulic accumulators out near the wing tip were cited. For the A330 and A340, British Aerospace is studying maneuver load alleviation (MLA) using the same surfaces, but the requirements reveal that much slower rates would be adequate. They stated that future designs could well require active flutter-suppression control modes.

The overall impression gained from Aero-spatale and British Aerospace was that the flight control systems of the A330 and A340 would be generally similar in nature to the A320. Much of the discussion that follows is based on the A320 flight control system because of the perceived similarity between the A320, A330, and A340 systems. Some A320 flight control figures are shown here (Figures 2.2-3 to 2.2-7).

The DLR IFG has developed the Automatic Flight Path Guidance (AFPG) system in order to lessen the demands on the pilot during flight. Pilots need automatic path guidance aids with functions and capacities above and beyond those of previous autopilot systems, particularly in relation to:

- Accuracy of guidance and accurately timed flying,
- High degree of maneuverability in automatic flight,
- Decoupling of the control axis,
- Consideration of the non-linearity of aircraft dynamics, and
- Adaptive properties.

AFPG is a powerful experimental flight control system for transport aircraft that was developed in recent years from a concept that comprises several measures for precise guidance control. The selected controller structure allows largely independent adjustment of the command and disturbance response as well as the eigenmodes of the controlled aircraft. The dynamic pre-control loop system derived from an analytical command model achieves a high degree of guidance accuracy with only a slight activity of the control elements. The controller structure includes direct compensation for any changes in aircraft configuration of flight condition, as well as gust disturbances. Controlled adaptation adjusts the controller gains of the inner loop and the outer control loops to the changing flight condition. The operation mode concept comprises controller modes with varying degrees of automation. The studies also cover higher-ranking functions in addition to the autopilot modes and control wheel steering, the basic operating mode where the pilot can intervene at any time by deflecting the control wheel to command changes in the

- Electrical Control

- Elevators
- Ailerons
- Roll Spoilers
- Tailplane Trim
- Slats and Flaps
- Speed Brakes/Lift Dumpers
- Trims

- Hydraulic Actuation of All Surfaces

- Mechanical Control

- Rudder
- Tailplane Trim (Reversionary Model)

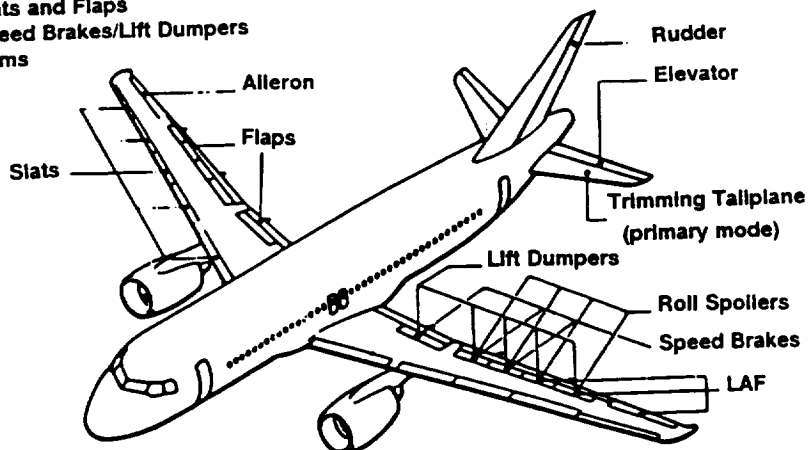


Figure 2.2-3. A320 Flight Control Surfaces

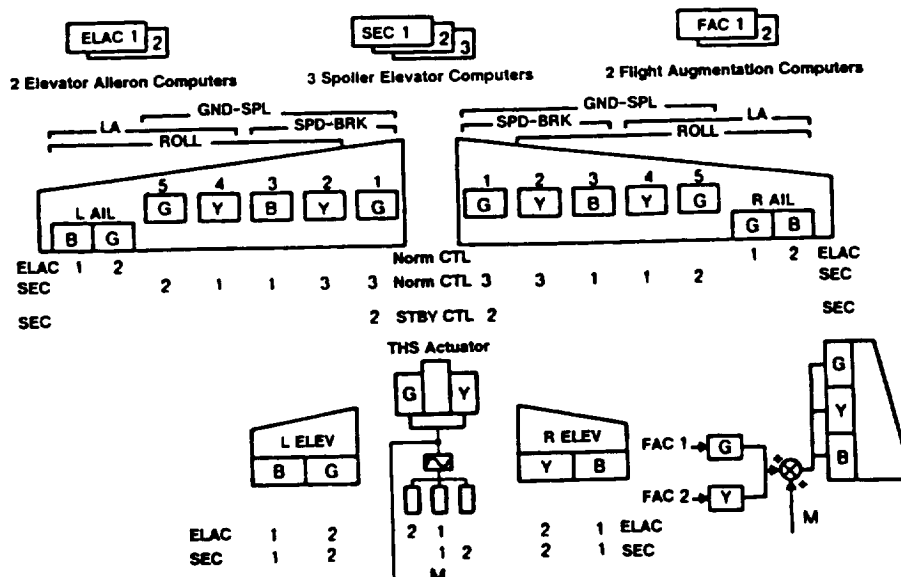


Figure 2.2-4. A320 Electronic Flight Control System (EFSC) Architecture

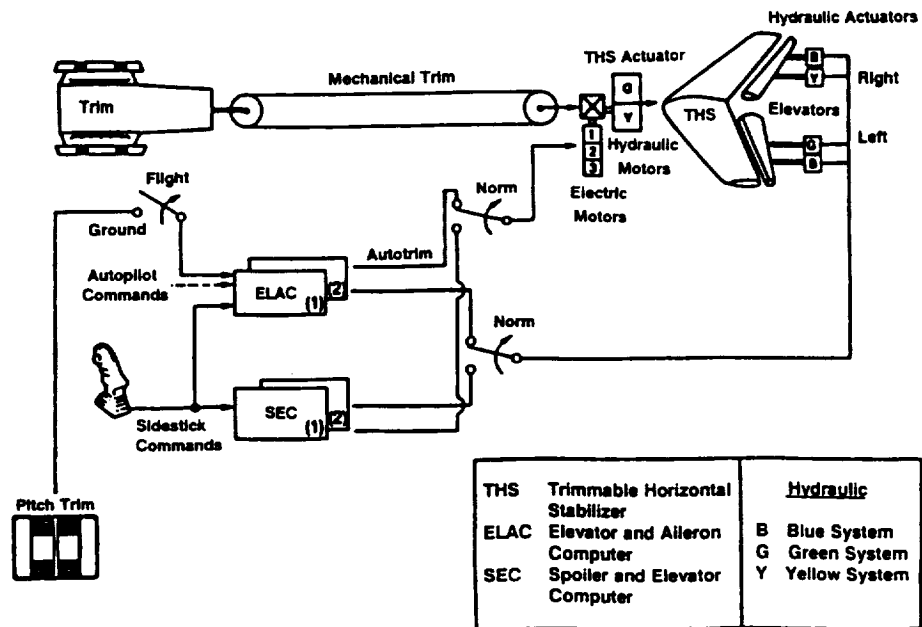


Figure 2.2-5. A320 Pitch Control

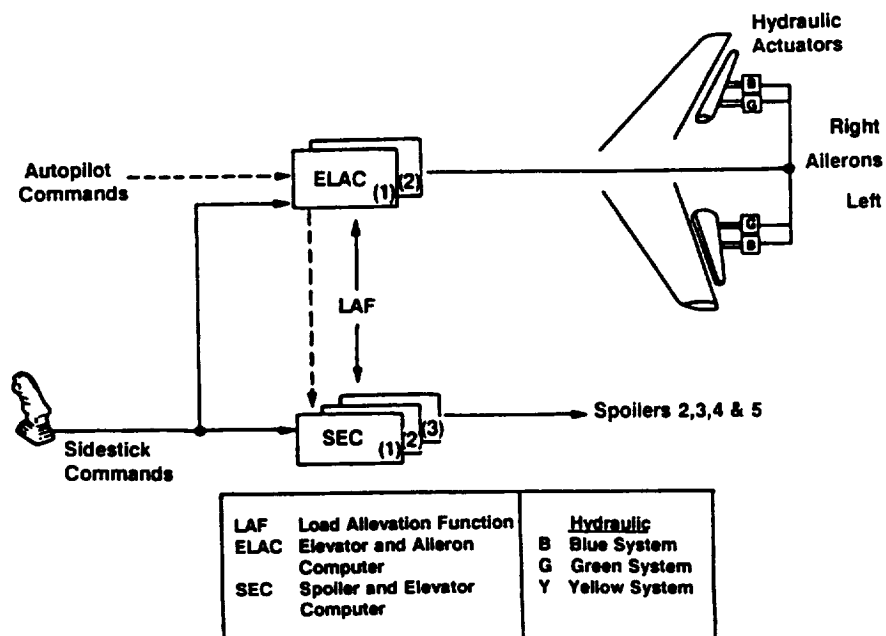


Figure 2.2-6. A320 Roll Control

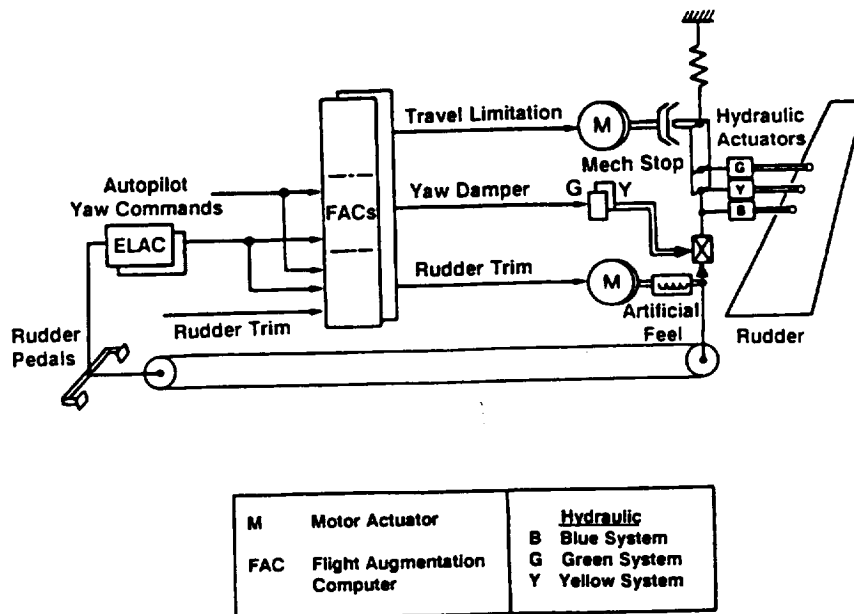


Figure 2.2-7. A320 Yaw Control

pitch and roll variables. These functions include automatic landing approach, go-around, and the accurately timed or fuel-optimum flying of specified flight paths.

The European community is working on a collaborative project involving 13 organizations from the countries of Britain, Germany, France, Italy, the Netherlands, Ireland, and Greece in an effort to evaluate fly-by-light (FBL) technology. A two-year Optical Data Transmission (ODT) program was started in February 1990. The objectives of this study are to:

- Define requirements for optical data transmission for civil aviation,
- Determine the state of the art of opto-electronics applicable to aeronautics,

- Produce a draft of component and data transmission system specifications and standards,
- Obtain experience in the manufacturing of harnesses and installation of optics into flight test stages,
- Define test procedures for use during opto-electronic system buildup, and
- Produce an equivalent optical ARINC 629 data bus.

The goal is to have optical technology ready for production by the year 2000.

FBL technologies have been pioneered by GEC Avionics, with a logical progression from laboratory systems to the SKYSHIP 600 system that has

been successfully flown by Airship Industries. This system uses proven control, monitoring, and computing principles applied via fiber-optic cables to control the surface actuator drive electronics. The pilot interface with the system is through a control column giving pitch and yaw control. The signals are processed to control the surface actuator drives in response to pilot commands. A pilot monitor panel provides lane-selection commands to a digital computer and also acts as a status indicator of the automatic system.

FBL is implemented in the data transmission process between the digital computer and the control surface actuator electronics. Signals are initially processed in conventional digital shaping circuits and then converted into optical data signals suitable for transmission along fiber-optic cables. Received optical signals are reconverted for processing either by the control surface actuator drive unit electronics or the flight control computer electronics. Multiplexing enables command data and monitored status information to be transmitted along the same data path. The FBL system on SKYSHIP 600 provides the following advantages:

- Greater immunity to lightning strikes and other sources of electromagnetic interference, even without the protection of a Faraday cage;
- Significant weight reduction in the flight control system; and
- Elimination of alignment flexing associated with mechanical control runs.

DLR has conducted a FBL demonstration using a fiber-optic link and successfully demonstrated an optical-to-electrical power conversion on a helicopter trim actuator for the tail rotor.

Deutsche Airbus' goal is to replace electrical transmission with optical systems for data acquisition and control. It is developing a highly redundant digital optical transmission system that uses networks of optical fibers to ensure that the system functions even if some of the data links fail. The company is also working with artificial intelligence for aircraft handling.

It is important to note that Aerospatiale is not in the business of optical sensors research, but will use them in its flight control system when the technology is ready. Optical data transfer between the control and actuator has been demonstrated in the laboratory.

The company has installed optical links with optical sensors and up to seven connectors on an Air Inter aircraft, as shown in Figure 2.2-8. These ride-along systems have accumulated more than 10,000 flying hours. The optical system uses 100/140 μm fiber. There is 70 m of fiber on the aircraft. The optical fibers have been tied to the electrical harness with standard electrical tie-downs, and the company says they have encountered no problems with the power budget or with mechanical failure of the fiber. The optical connectors are terminated with epoxy, and there is a need for a better, more efficient method.

Future flight controls will take advantage of new techniques such as electromechanical actuators (EMAs) and electrohydrostatic actuators (EHAs) which are illustrated in Figure 2.2-9.

2.3 NAVIGATION AND COMMUNICATIONS SYSTEMS

2.3.1 Overview

The wide variety of demands imposed on air traffic (e.g., economy and environmental tolerability)

- 7 Connectors
- Bit error rate < 10⁻⁹
- More than 3500 hrs in flight
- Signal Manchester bi-phase 500 kb/sec
- 70 m of optical cable with 100/140 μ m optical fiber

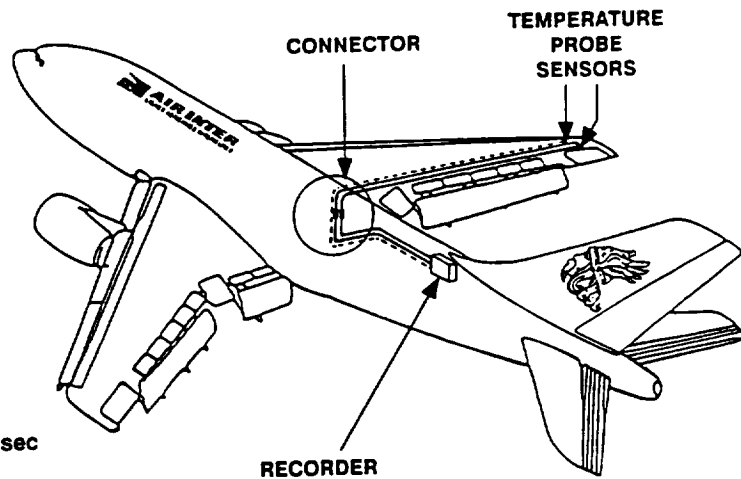


Figure 2.2-8. Optical Control System Installed by Aerospatiale on the Air Inter Aircraft

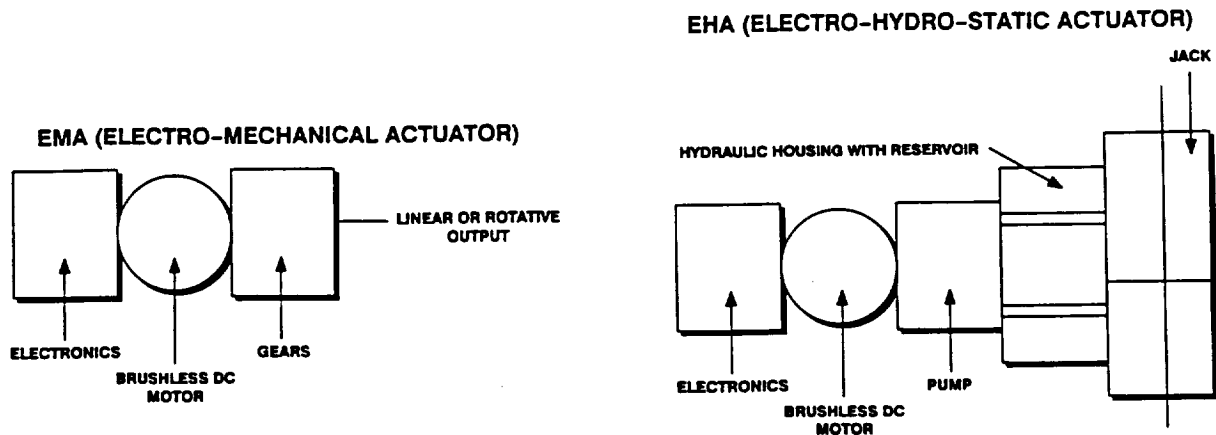


Figure 2.2-9. Advanced Actuator Concepts

necessitate constant improvement of air traffic control and navigation systems. Improvement in navigation systems is achieved by integrating systems, such as inertial and radio navigation systems. In principle, there are two different ways to achieve improvements: develop completely new navigation systems or make more efficient use of available systems. Aircraft operations can be significantly improved by connecting the flight

management computer (FMC) to a datalink network. Air traffic control can use the link to pass flight plan changes with improved accuracy and effectiveness. Designing the FMC datalink interface so that it can be changed easily enables individual airlines to customize their use of the FMC to match particular operational needs. Many European companies are focusing on this area of research to improve navigation.

European research in voice communications appears to be limited, with the primary focus of the research being the use of voice communications in satellite communications. However, research is under way in many European companies to develop technologies for higher-capacity datalink communications to meet the new standards being developed by ARINC (up to 10 MB/sec).

2.3.2 Program Specifics

Smiths Industries is developing the Flight management computer datalink interface (FMCDI) to pass data in both directions between aircraft flight management computers, ATCs, and airline operations centers. Using this datalink interface, the FMCs can be preloaded with information relating to route, weight, and meteorological factors. The datalink will also enable ATCs to uplink route changes, such as an alternative approach procedure, into aircraft FMCs where they will be presented on the control and display unit of the FMC. The downlink between FMCs and ATC centers can be used to report, automatically if necessary, aircraft position and other operating data such as the currently derived wind vector.

The two-way link is not just of benefit to the particular aircraft equipped with the system. ATC centers can process downlinked data for the benefit of all aircraft aloft. Aircraft positions can be determined with greater accuracy, and up-to-the-minute data on wind and temperature strata will be available.

When developing datalink specifications, the requirements of each of the world's airlines had to be considered. Different levels of usage ranging from basic to comprehensive had to be accommodated. Variations in usage require variations in the software, which adds to the problem of certification. The solution was to define uplink, downlink, and

other operational factors by means of "loadable" tables.

Smiths Industries has a flight management computer in place on the B-737. All uplink and downlink data, trigger characteristics, and datalink-specific display prompts are controlled by loadable tables within the FMC's memory. The configuration of the datalink can be altered by loading new tables via the on-board data loader, an operation similar to loading navigational data into the FMC.

Intensive work is currently in progress at DLR IFG in the following technology areas:

- Interference-free image data transmissions for flight guidance and reconnaissance.
- Integrating the outputs of the Global Positioning System (GPS) by using the coarse acquisition (C/A) code with an inertial navigation system (INS), distance measuring equipment (DME), and the radar altimeter.
- New sensors for inertial navigation systems, most notably the ring laser gyroscope. DLR has extensive test facilities for advanced sensor and gyroscopic technologies. In particular, the modular strapdown system (MOSY) is a significant development in the area of sensor testing equipment.

Long-term objectives of the research activities at DLR IRG include the following:

- Integration and testing of a laser gyroscope developed in-house using MOSY in preparation for system development work in German industry.
- Testing of dynamically tuned gyroscopes in the laboratory and in helicopters as a basis

for industrial development of a strapdown navigation system aided by Doppler radar.

- Integration of strapdown systems into a digital, redundant flight guidance system to realize the full potential of this technique.

Research has found that on-board dead-reckoning navigation systems supported by DME are particularly suitable for investigating the concept of integrating current systems. The simplest system of this type that was studied is an integrated navigation system that used measured true airspeed, compass course, and estimated wind velocity and direction. A Kalman filter, used for the integration, estimated sensor errors and wind components. The advantages of such a system, which is illustrated in Figure 2.3-1, are:

- The position accuracy achieved is better than 100 meters (1-sigma).
- Navigation is not interrupted by the failure of one DME ground station.
- The wind is estimated continuously and with improved accuracy by the Kalman filter and is thus known on board.

Test flights performed over Northern Germany have shown that the integrated navigation system does not improve the navigation accuracy to any great extent over that of the simple air data navigation system. Kalman filter calculations have so far only been performed off-line. Work is currently in progress on implementing an on-line system.

The DLR IFG is investigating future alternatives for navigation systems currently in use. DLR developed and successfully applied a method for evaluating ground-based radio navigation systems

with the aim of achieving a specified system performance at the lowest possible cost, while ensuring that maximum permissible errors are not exceeded at specified points.

For applications being examined, the problem is to find a suitable configuration of the navigation systems studied. The evaluation method yields the following results:

- Preferred locations and areas for installation of the navigation systems;
- Minimum (i.e., optimum-cost) number of stations required for non-redundant and redundant configurations; and
- Total cost of each potential configuration for various alternative systems.

DLR IFG is investigating new sensor types for inertial navigation systems. Of particular interest is the ring laser gyroscope, an outstanding measuring device with a high dynamic range (3×10^{-6} deg/sec to 1,000 deg/sec) and insensitivity to external vibrations, acceleration, and temperature changes. The ring laser gyroscope produces a digital output that eliminates errors associated with A-D data conversion. One notable problem with the laser gyroscope is the "lock in" effect. While this effect cannot be eliminated entirely, DLR IFG is doing intensive research into reducing the problem as much as possible. Work thus far has concentrated on using magneto-optical elements to influence the laser beam in reflection (the magneto-optical Kerr effect) and in transmission (the magneto-optical Faraday effect). Effectiveness of both methods has been demonstrated using laser gyroscope concepts developed specifically for this purpose, although the results are not yet satisfactory for operational systems. Current efforts are to combine both methods by means of a magneto-optical Faraday mirror. Research on modular ring laser

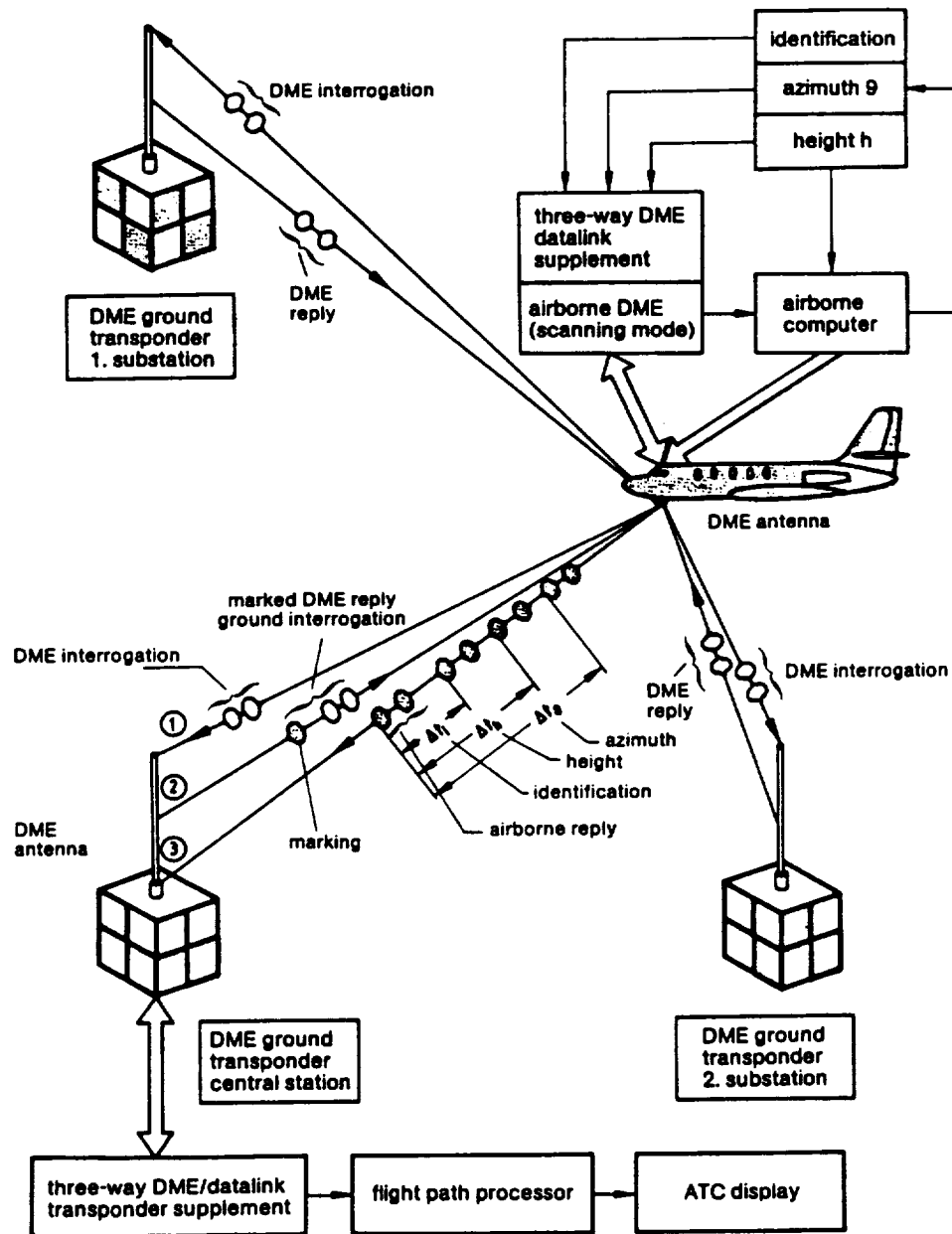


Figure 2.3.1. A Dead-Reckoning Navigation System Supported by DME

gyroscopes is being pursued at DLR IFG in an attempt to reduce the expense of the ring laser gyroscope. Advantages of modular ring laser gyroscopes are:

- The potential measuring accuracy of components with reduced manufacturing accuracy can be increased even under changing environmental conditions if the beam geometry in the resonator block can be largely stabilized by control techniques.
- Each component (mirror module, tube, block) can be made of the materials most suitable for its specific requirements so that high-vacuum problems are restricted to the gas discharge tube.
- The modular concept allows the use of many different techniques for avoiding the lock-in effect ("dither drive", magnetic mirrors, etc.) and thus represents an ideal "test bed" for research.

DLR IFG has extensive test facilities for the research and development of new gyroscope technologies (laser, fiber-optic, etc). Test facilities are temperature-controlled and can produce interference magnetic fields five times greater than that of the Earth. The MOSY experimental modular strap-down system was developed to test strapdown sensors. It is characterized by six sensors accommodated in separate, temperature-controlled modules. Each sensor can be tested on the gyroscope individually, or as a complete system.

Sextant Avionique Ring Laser Gyro guidance systems were installed on the Adriane launch vehicle system beginning in 1979. ONERA is actively developing RAMSES, a multi-band airborne instrumentation radar with simultaneous operation in several radar bands. There is no correlation or

image fusion between bands, merely image comparison. RAMSES provides a complete polarization matrix and uses variable waveforms. While the applications are primarily military, RAMSES may also be useful in commercial applications.

ONERA's work on the Radar Impulsion Antenna Synthetique (RIAS) may have application in ATC. In the surveillance mode, it transmits data to the tracking computer, which can track 100 to 200 targets simultaneously.

GEC's tactical routing algorithm (TARA) provides support to aircrews in airborne route planning and replanning, thus reducing cockpit workload by the rapid derivation of minimum cost routing.

As part of TARA's airborne route planning, aircrew are invited to define the end objective, desired intermediate waypoints, and updated prohibited transit areas. All further activity is fully automated. TARA accesses its terrain and updated intelligence database to derive the optimum route. TARA considers parameters such as the following, which can be prioritized to reflect their relative importance to a particular aircraft operation:

- Fuel costs,
- Time costs,
- Obstructions,
- Aircraft performance,
- Prohibited transit areas, and
- Intervening waypoints.

A best first search technique is employed to discover the optimum route, with continuous fine-tuning of the search parameters to meet the changing requirements of local scenarios. Waypoint-to-waypoint routing is displayed to the aircrew on a video map, and steering information to maintain the route is provided by flight director symbology.

2.4 DISPLAY SYSTEMS

Advanced display systems are necessary to enhance aircraft control and reduce pilot workload. This section addresses several key technological issues in the area of aircraft display systems.

2.4.1 Overview

From the pilot's point of view, there are several key issues in the area of aircraft display systems. Display systems needed for enhanced aircraft control include head-up displays (HUDs), helmet mounted displays (HMDs) and night vision goggles (NVGs). Another display system of importance is flat panel displays (FPDs). Touch-sensitive flat panel displays permit multifunction displays without bulky push buttons, thus making panels easier to operate, read, and understand.

HUDs have operational advantages for commercial aircraft. During adverse weather conditions, the pilot can simultaneously monitor instrument-generated symbology concerning, for example, the runway centerline (landing), while still monitoring available external cues such as runway lights. HUDs can also provide deceleration data during landing rollout and early warnings of wind shear.

FPD technologies that have potential for use in the cockpit include:

- Liquid crystals,
- Electroluminescence,
- Gas plasma, and
- Vacuum microelectronics.

LCD technology is the most promising technology for wide-spread use. Investigations into the

research and development of LCD technology for data display panels, as well as multifunction CRT control and display units and dot-matrix display techniques, are currently underway. These technologies are the basis for LED arrays to replicate pointer-on-dial instruments, and active matrix liquid crystal displays (AMLCDs).

Touch-sensitive FPDs enable multifunction displays without the familiar circle of push-buttons surrounding the screen. This technology is still primarily in the research stage because of concerns such as the possibility of inadvertent entries due to air turbulence.

Several key areas concerning aircraft controls include the principle of hands-on-the-throttle-and-stick (HOTAS), voice technology (speech recognition and generation), and the use of artificial intelligence for aiding pilots in decision making.

HOTAS has become an aircraft cockpit design must, enabling the pilot to maneuver the aircraft without having to move his hands from the throttle or stick to some other location in the cockpit. This results in a highly efficient man-machine interface. It allows the pilot to perform under much less stress and a lower workload. This design principle has been widely accepted in the free world for several years although it was not mentioned specifically by any of the companies visited by the NASA panel.

One of the longer-term issues in pilot control of aircraft is the use of artificial intelligence to aid pilot decision making. Displays would only present the pilot with threats of immediate importance dependent upon his workload level. Voice warnings would be interactive, allowing the pilot to ask questions and receive answers or suggestions prioritized by their relative importance to the current situation. None of the companies visited by the NASA panel specifically mentioned this technology.

2.4.2 Program Specifics

GEC Avionics is highly advanced in the areas of HMD systems, NVG, Forward-Looking Infrared Radar (FLIR), HUD systems, and advanced man-machine interface (MMI) research.

Cats Eyes is GEC Avionics' name for their primary NVG system. The system offers full binocular night vision and direct vision with electro-optical image overlay. It is compatible with holographic HUDs and full-color displays, and it provides wraparound peripheral vision. A new optical technique presents electro-optical imagery from a conventional image intensifier tube on a transparent combiner in front of each eye so that images are superimposed in front of each eye with the outside world on a 1:1 scale. Unlike conventional NVGs, Cats Eyes allows the pilot to view the HUD symbology directly with no resolution loss. Figure 2.4-1 shows a typical HMD with NVG capability.



Figure 2.4-1. A Typical HMD with NVG Capability

GEC Avionics is quite proud of being selected to provide the HUD for the U.S. Air

Force's LANTIRN program. The field of vision (FOV) for this HUD is 30° by 18° . The dual-mode LANTIRN HUDs provide full cursive flight symbology in raster mode, written in the flyback period of the CRT. The 525-line standard can be converted to 875 lines if required. A typical HUD symbology display is illustrated in Figure 2.4-2.

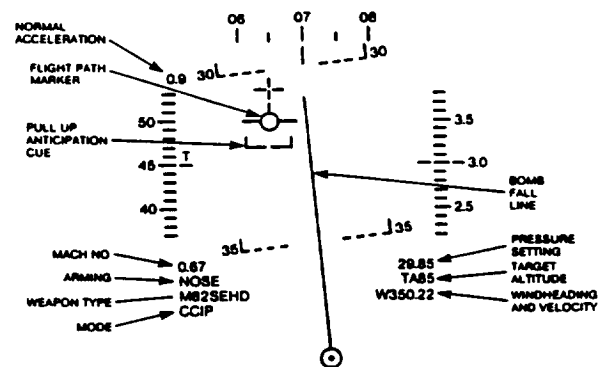


Figure 2.4-2. Typical HUD Symbology

A GEC Avionics HUD is being employed in the McDonnell Douglas C-17. It is coaming-mounted for the pilot and copilot, and the combiners fold down for cross-cockpit visibility. The HUD unit is 35 in. long, 10 in. wide, and 13.5 in. deep (the maximum depth at the combiner). It weighs 54 lb, employs a single line replaceable unit (LRU) with a built-in processor, and consumes 100 W of single-phase power at 115 V and 400 Hz. The total and instantaneous fields of view (TFOV, IFOV) are fairly wide--TFOV is 30° in azimuth by 24° in elevation. Transmission through the combiners is 80%, and the graded coatings on the combiners help eliminate banding. The HUD's mature mean time between failure (MTBF) is 7,000 hours. The HUD incorporates twin 1750A processors and a 1552B interface. Module substitution will allow the HUD system expansion to provide raster video from electro-optic sensors with the flight symbology overwritten in stroke. The HUD was designed to achieve 10^{-9} critical failures per

Table 2.4-1. Sextant Avionique HUDs for the A320 and the A330/340 Compared

	A320 HUD Optical Head Unit	A330/A240 HUD Optical Head Unit	A320 HUD Computer	A330/A240 HUD Computer
Weight	10.5 kg	10 kg	5 kg	5 kg
FOV/IFOV	24° x 15°; depends on mechanical installation	?/30° x 20°	–	–
Power Supply	115 V, 400 Hz 28 Vdc, 0.6 A	115 V, 400 Hz 28 Vdc, 0.6 A	115 V, 400 Hz	115 V, 400 Hz
Environment	Complies with DO 160 A	Complies with DO 160 B	–	Complies with DO 160 B
Power Consumption	–	60 W max	56 W	56 W
Interfaces	–	–	ARINC 429 (I/O); Discretes (I/O)	ARINC 429 (I/O); Discretes (I/O)

hour, is electronically boresighted, and is cooled by forced air and convection.

Sextant Avionique claims to have pioneered the development and production of HUDs for commercial aircraft. They produce two separate HUDs for the Airbus 320 and the A330/A340. Table 2.4-1 compares these two HUDs.

Sextant Avionique has developed a smart head-up display (SHUD) system, and they are also working on advanced head-level/head-up (HL/ HUD) displays. The SHUD is fully integrated and housed in one LRU from the data bus interface to the CRT. It is fully compatible for both day and night (stroke/raster) operations. The LRU takes care of several functions, including picture generation (CRT very high voltage power supply), collimation (optics), data computation, display processing, digital bus interface, and the up-front control panel. The Sextant Avionique SHUD weighs only 13 kg. The total field of view is 24°.

Sextant Avionique proposes two areas for growth regarding their SHUD: the holographic combiner and the ability to record through a video camera.

Sextant Avionique combined HL/ HUD seems to be a break-through in modern fighter aircraft display concepts. The head-level display (HLD) module, designated the TMM 1410, is a self-contained, multimode, monochromatic, and collimated display. The field of view for the HLD is 14° by 10°. The TMM 1410 HLD can be integrated with a choice of two Sextant Avionique HUD models. One of these, the VEM 130, is monochromatic and multimode with a 24° circular FOV. The other HUD, designated the VEH 3020, is monochromatic and multimodal and employs refractive optics (holographic), with a FOV of 30° by 20°.

Sextant Avionique's HMD system has several operational benefits. It has night navigation capabilities, flight information symbology, and visual

acquisition (reverse cuing). The HMD system is available in three different configurations:

- An integrated helmet sight system,
- An integrated helmet sight/display system, and
- An integrated night vision helmet sight/display system.

Table 2.4-2 compares these three options. Sextant Avionique leads the European efforts in FPD R&D as evidenced by their LCD production facility in Grenoble, France, and their advanced applications of LCD technology in the aircraft cockpit.

Smiths Industries has been involved in the aircraft displays business since the "first decade of powered heavier-than-air flight." Specifically, Smiths Industries has been involved in the development of the HUD since the early 1960s. Smiths Industries is aware of the key issues involved in the development of HMD technology. Evidence of an active R&D effort in this area was not obtained. Smiths Industries has stated that it is "demonstrating the cautious approach to the integrated helmet." It is addressing integrated HMD problems such as weight, balance, and ejection safety by "thorough examination of new enabling technologies aimed at the second-generation fully integrated HMD." The nature of this thorough examination is unknown.

Tables 2.4-3 and 2.4-4 list the specifications of four specific Smiths Industries products. Table 2.4-3 lists the specifications for the Type 1501 and Type 1502 HUDs. Table 2.4-4 lists specifications for the Type 2100 color multifunction display and the 3000 Series color multifunction display.

Three technologies currently lead Smiths Industries' production of displays and associated systems:

- Current flight management systems employ multifunction CRT control and display units,
- Dot-matrix technique as the basis for LED arrays to replicate pointer-on-dial instruments, and
- LCD technology as arrays for data display panels and/or discrete instruments.

Smiths Industries' primary flight displays use color CRTs. Engine and systems displays use either CRTs, dot-matrix LED arrays, or LCDs. Fuel quantity indication and management control panels as well as fuel and de-fuel indication control panels use either LEDs or LCDs. Electronic library and flight management system control and display panels both use CRTs. Smiths Industries' next-generation flight deck equipment will probably include large-area displays that take advantage of the promising LCD technology to provide large display areas with minimum depth.

Smiths Industries' two most significant areas of research and development in future displays technology involve the active matrix liquid crystal display (AMLCD) and the HMD. Smiths Industries was one of the first to invest in FPD technologies incorporating LCDs for aerospace applications. LCDs have the ability to maintain acceptable display brightness during high ambient light levels (up to 10,000 foot-Lambert light levels of direct sunlight).

AMLCDs have fluorescent light illumination that is controlled by sensors for ambient light level that adapt the display to varying cockpit light levels, from low NVG levels to direct sunlight. This display ability along with the larger effective display area has convinced Smith Industries that LCDs will continue to displace CRTs in the future.

Table 2.4-2. Comparison of Sextant Avionique HMD Systems

	Integrated Helmet Sight System	Integrated Helmet Sight/Display System	Integrated Night Vision Helmet Sight/Display System
Field of Regard	360°	360°	360°
Field of View	6° modular	20° modular	40° × 30° binocular
Symbology	Aiming and warning reticles - Directly projected on the visor	High contrast stroke	Stroke
Line-of-Sight Accuracy	0.7° (at 95%)	0.7° (at 95%)	0.7° (at 95%)
Helmet Weight	1.3 kg (2.9 lb)	1.6 kg (3.5 lb)	2.2 kg (4.8 lb)
Other	-	-	<ul style="list-style-type: none"> • Raster display (FLIR or TV) • Integrated light intensifier tubes

Table 2.4-3. Comparison of SI Type 1501 and 1502 HUDs

	Type 1501 HUD	Type 1502 HUD
Optical System	Exit Lens Size: 177 mm (7.0 in.) diameter aperture truncated to 108 mm (4.25 in.) fore and aft TFOV: 22° IFOV: 20°(H) × 16°(V)	Exit Lens Size: 140 mm (5.51 in.) diameter aperture truncated to 108 mm (4.25 in.) fore and aft TFOV: 25° Binocular IFOV: 20°(H) × 16°(V)
Accuracy	1.0 mrad on axis 2.0 mrad at 6° 3.2 mrad at 9° 4.0 mrad at 11° Combiner Assembly <0.25 mrad (distortion)	
Parallax	Display parallax generally <1 mrad	
Color	Green P1 phosphor	Green (P53 phosphor)
Brightness	Brightness levels of the symbology and the raster video are independently controllable	Full readability in ambient light of 10,000 fL (35,000 cd/m ²)
Writing Speed	Stroke - 38,000°/sec	16,800°/sec
Frame Rate	Stroke - 60 Hz	50 Hz

Table 2.4-3. Comparison of SI Type 1501 and 1502 HUDs (continued)

	Type 1501 HUD	Type 1502 HUD
Line Width	Stroke 0.8 ± 0.2 mrad at 1,000 fL	Less than 0.1 mrad at 4,000 cd/m ²
Mass	17.7 kg (39.9 lb)	11.3 kg (25 lb)
Raster Format	Raster Video - 525 lines 60 fields/sec 2:1 interlace 625 lines 50 fields/sec 2:1 interlace	525 lines, 60 Hz 625 lines, 50 Hz
Cooling	20 ft ³ /min cooling flow rate at maximum inlet air temperature of +56°C	
Environment	Generally in accordance with MIL-T-5422F	Generally in accordance with MIL-E-5400T and MIL-STD-810C
MTBF	>2,000 operating hrs	>2,000 hrs
Power Requirements/Consumption	115/200 V, 400 Hz, 3-phase ac, 100 VA max, 28 Vdc, 2 W	28 Vdc, 120 W max, reconfigurable for ac supply

Table 2.4-4. Comparison of SI Type 2100 and 3000 Series Color MFDs

	Type 2100 Color MFD	3000 Series Color MFD
Usable Screen Area	5 in. x 5 in. (127 mm x 127 mm)	5 in. x 5 in. (125 mm x 125 mm)
Number of Colors		Any 15
Viewing Angle	$\pm 16^\circ$ horizontally 0° to 30° vertically	$\pm 53^\circ$ horizontally 0° to 35° vertically
Resolution	Raster - 65 line pairs/in.	Screen - 0.012 in. (0.3 mm) nominal
Line Width	Stroke - 0.016 in. to 0.018 in. over half to full brightness. Not less than 0.012 in. over full range	Less than 0.024 in. (0.6 mm) at all brightness levels
Writing Speed	Up to 0.8 mm/ μ sec	Cursive symbology 0.043 in. (1.1 mm)/ μ sec Raster shading 0.091 in. (2.3 mm)/ μ sec
Viewable	From starlight to 10,000 lm/ft ²	
Brightness	Uniformity better than $\pm 15\%$	Illumination - 86,400 lm (max)
Refresh Rate		70 Hz (Shading 37/70 Hz)

Table 2.4-4. Comparison of SI Type 2100 and 3000 Series Color MFDs (continued)

	Type 2100 Color MFD	3000 Series Color MFD
Formal Jitter		Less than 0.0079 in. (0.2 mm)
Convergence		Less than 0.012 in. (0.3 mm) misconvergence
Discrimination		Greater than 1.0 at max illumination
Resolution		Position 0.002 in. (0.053 mm) Vector 0.016 in. (0.425 mm) Angle 0.088°
Linearity		± 1.0%
Input Power	200 V, 3-phase, 4-wire, 400 Hz, 180 VA	115 V/200 V, 400 Hz, 3-phase, 200 VA
Cooling	Forced air cooled	1.628 lb (0.74 kg)/min with pressure drop of 25 ± 50 pascal
Mass	24 lb (10.9 kg)	Not exceeding 22 lb (10 kg)
Interfacing	<u>Video</u> RGB 525 line 30/50 Hz 625 line 25/50 Hz 875 line 30/60 Hz <u>Stroke</u> Dual X/Y and bright-up analogue inputs <u>Raster/Stroke</u> Discrete signal data Dual serial data channels (I/O)	
Dimensions	6.72 in. (170.7 mm) × 7.07 in. (179.6 mm) × 15.25 in. (387.4 mm)	6.38 in. (162 mm) × 6.38 in. (162 mm) × 12.5 in. (317 mm)
Reliability	MTBF in excess of 3,000 hours	Predicted MTBF 2,500 hours
Environmental	Specification designed to MIL-E-5400T and MIL-STD-810C	Specifications generally in accordance with MIL-STD-810C or BS3G100

Smiths Industries has been active in LCD development since the early 1980s for both military and commercial aircraft applications. During this time, three different LCD technologies have been employed, including single-cell dichroic, dual-cell dichroic, and twisted nematic. Many aircraft have used these LCD-based displays, including the B-737, B-757, B-767, A-4, F-4, C-130, HH-1, and AH-6.

Smiths Industries is convinced that the large interactive cockpit displays of the future, which need to provide real-time quality color information to the pilot, will require advanced technology such as AMLCD.

Smiths Industries has already produced the intelligent control display unit (ICDU), an FPD that

uses AMLCD technology. The ICDU is controlled by a 32-bit processor with 1 MB of memory and uses Ada programming to meet a wide scope of operating requirements such as area navigation, storage of management and communication/navigation control information, and integrated navigation using inertial, GPS, and other sensors.

The display screen of the ICDU is readable in sunlight, is NVG compatible, and is bit-mapped for alphanumerics/graphics. The display uses active matrix twisted nematic LCDs. Screen resolution is 80 dots/in. over an active area of 2 in. x 3 in. with a refresh rate of 100 Hz. The unit is 7.125 in. high, 5.75 in. wide, and 5.9 in. deep; it weighs only 9 lb.; and it can interface with either MIL-STD-1553 or ARINC 429 data buses. The ICDU was designed to allow growth within existing dimensions, which are considerably smaller than equivalent displays using conventional technology.

GEC Avionics' Alpha helmet-mounted sight (HMS), shown in Figure 2.4-3, consists of their Alpha helmet plus an aiming system that enables the pilot to point on-board sensors by simply moving his head. This sighting and cuing information is presented to the pilot on the inner surface of his clear visor. A high-brightness LED reticle is relayed by a prism and then reflected onto a dichroic patch coated on the inner surface of the visor. The Alpha sight system fits into the standard Alpha helmet with minimum changes and adds only 130 g of weight to the helmet. The system maintains ejection integrity and is compatible with magnetic tracker systems and eyeglasses. A schematic of how the Alpha HMS ties into the aircraft avionics system is illustrated in Figure 2.4-4.

GEC Avionics' Knighthelm helmet-mounted system can be configured to provide:

- NVG only;
- NVG and symbology;

- NVG, FLIR, and symbology;
- Day high-brightness symbology; and
- Dual day and night use.

When using Knighthelm in a configuration that incorporates CRTs or a helmet-mounted head-tracker receiver, a quick-release connector ensures safe ejection and fast egress. A single LRU performs helmet CRT processing and driving (slow stroke and fast stroke over raster), head tracking, interface, and scan conversion.

Sextant Avionique offers military and commercial HUDs, including one for the Airbus A320. This device, with automatic brightness control and extensive BIT capability, has a 24° x 15° field of view and an MTBF of 5,000 hrs.

Sextant Avionique is developing a voice interactive system with the following characteristics:

- Connected-word recognition,
- 100 words, expandable up to 400 words,
- Response time less than 400 ms,
- Reference memory with battery backup,
- Synthesis of 200 sec of speech,
- A multiplexed bus coupler, and
- Two RS 422 lines.

Sextant Avionique claims that successful sentence recognition is better than 95%, with word confusion rate less than 2%, and word rejection less than 3%. The complexity and number of conventional channels of communication between the pilot and cockpit as well as the reduction of available surfaces within the cockpit for more controls and displays are two significant issues that this voice interactive system intends to address.

Sextant Avionique's DRACAR digital map generator can be used in automatic or manual mode, providing an out-of-the-window view computed according to aircraft movements in the auto-

Overview

- Developed for MOD(PE) for flight trials in Q2 1989
- Based on lightweight Alpha helmet
- Minor modifications only to basic helmet shell
- Low additional weight-100g

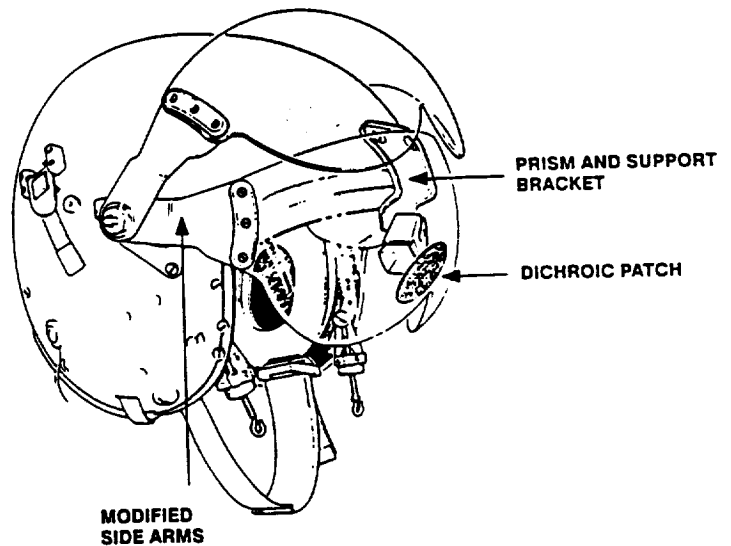


Figure 2.4-3. Alpha HMS

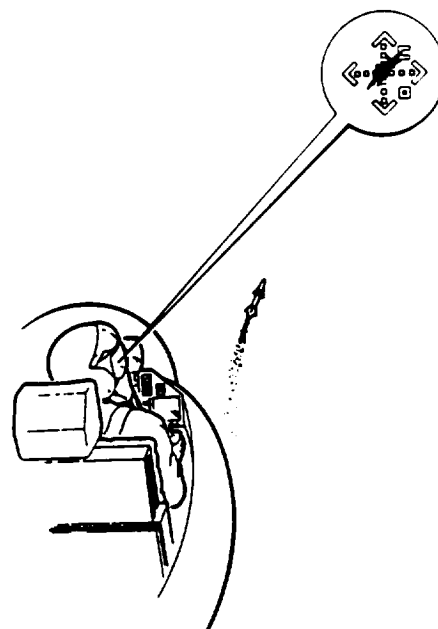
matic mode, and a variable environment in which reference points of view can be slewed in the manual mode. DRACAR's 3-D images for HUDs can be superimposed with outside scenery from sensor imagery such as forward-looking infrared radar FLIR data. Specific digital modes include features declutter, elevation color coding, terrain slope shading, and terrain profile. Display resolution is 512 by 512 pixels, and its computation rate is 20 Hz. Video standards are up to 60 Hz N.I. Coverage includes 50,000 km² (100 k) and 3,000,000 km² (250 k). The scale change duration is 1 sec, and the mode switching duration is 50 ms.

GEC Avionics' Technology and Systems Research Laboratory (TSRL) and Airborne Display Division (ADD) have recently used the technology to design and build a demonstrator of an off-axis HUD with a fairly large field of view (FOV) and minimum constraints on head motion by the pilot. TSRL is also very active in HMD design, completing several different HMD designs since 1990, including the following:

- A 50° FOV HMD with eye tracker optics for helicopter and simulation applications,
- A lightweight HMS for target designation for fixed-wing applications,
- A HMD to assist divers in murky waters by providing a low-light-level TV image to one eye,
- An integrated night vision helmet that superimposes symbology over a 40° FOV intensified outside world scene,
- An HMD demonstrator that uses the helmet's visor as the image combination surface,
- A laser-illuminated HMS that employs holographic optics and an electronically addressed spatial light modulator to decrease total HMD weight, and

- A fiber-optic HMD to assess the feasibility of practical applications of full-color HMDs.

Virtual cockpit research is also a significant part of TSRL's research. A typical virtual cockpit display is shown in Figure 2.4-5. Their effort in this area involves a visual simulation of the pilot's cockpit environment displayed, often in 3-D, on an HMD. TSRL's flight path demonstration displays a projected flight path that converges to infinity and gives velocity feedback by scrolling forward at a variable rate. Two-dimensional systems status displays appear on a space-stabilized panel, while the artificial horizon, heading display, and pitch bars are focused at infinity. Other aircraft are presented in the display with position and motion information. Distant aircraft are represented geometrically until they are close enough to be represented pictorially. All display elements change appropriately with pilot head movement to ensure a fully space-stabilized display. TSRL has also researched the use of voice recognition and synthesis to interact with and control the displays.



The GEC Avionics control and display unit (CDU) is an interactive keyboard and display unit designed to control avionic systems such as:

- Navigation and flight management systems;
- Control, communications, and identification;
- Moving map control; and
- In-flight fault-analysis systems.

The CDU can interface with the MIL-STD-1553B, ARINC 429, and RS423 data buses. Other interfaces are available through consultation with GEC Avionics. The unit contains a 16-bit processor and an extensive interactive test mode with BIT capability to ensure that over 95% of faults are detected at first line.

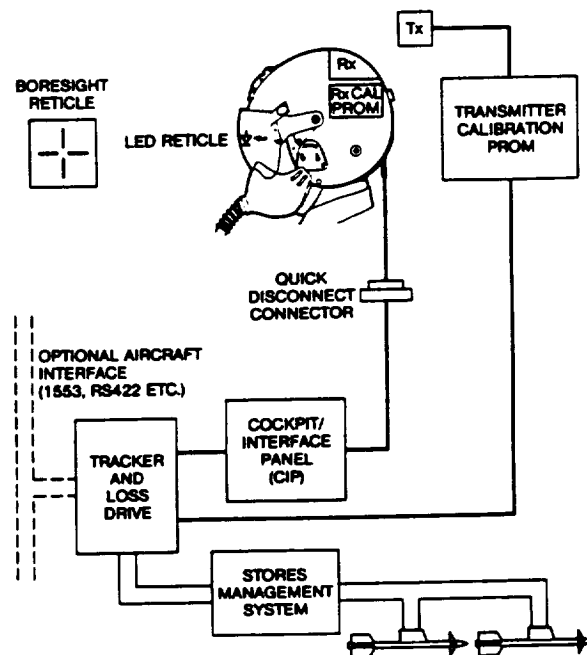


Figure 2.4-4. Alpha HMS Schematic

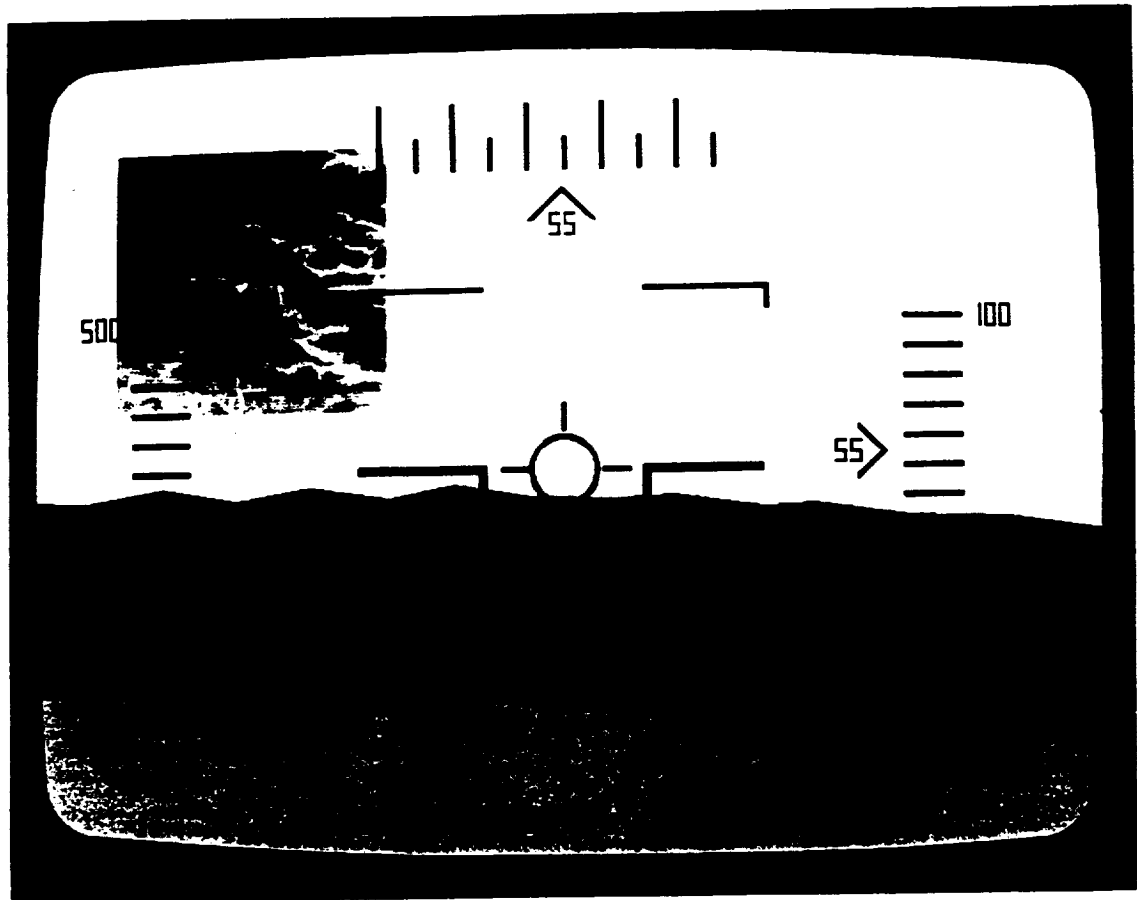


Figure 2.4-5. Virtual Cockpit Display

The CDU display module is an addressable 230×230 pixel array incorporating supertwist LCD elements with driver electronics, backlighting, heater, and temperature sensor. The heater allows rapid start-up of the LCD at low temperatures (-40°C) with no degradation in performance. The backlight allows readability of the display over the range 0.1 to 100,000 lux. The display is compatible with NVG, if necessary. It is 5.75 in. wide, 5.25 in. high, and 5.25 in. deep; it weighs 5.5 lb; and it can operate over a temperature range of -40°C to $+55^{\circ}\text{C}$.

EPOPEE III is a French national program under the leadership of Aerospatiale. Partners

include Aerospatiale Avionic and System Directorate, Sfena, Thomson-CSF, and Crouzet.

EPOPEE III is retrofitting a simulator with advanced controls and displays using a new cockpit layout with short-motion controls (e.g., side-stick controllers) and speed rate controls (e.g., throttle). Aerospatiale's cockpit development methodology is shown in Figure 2.4-6.

The fixed-base simulator used for EPOPEE III employs an all-glass cockpit configuration similar to that in the A320 and A321 aircraft. The simulator toured by the NASA panel (it is unknown whether or not this was the same configuration used under the EPOPEE III project) contained, at the

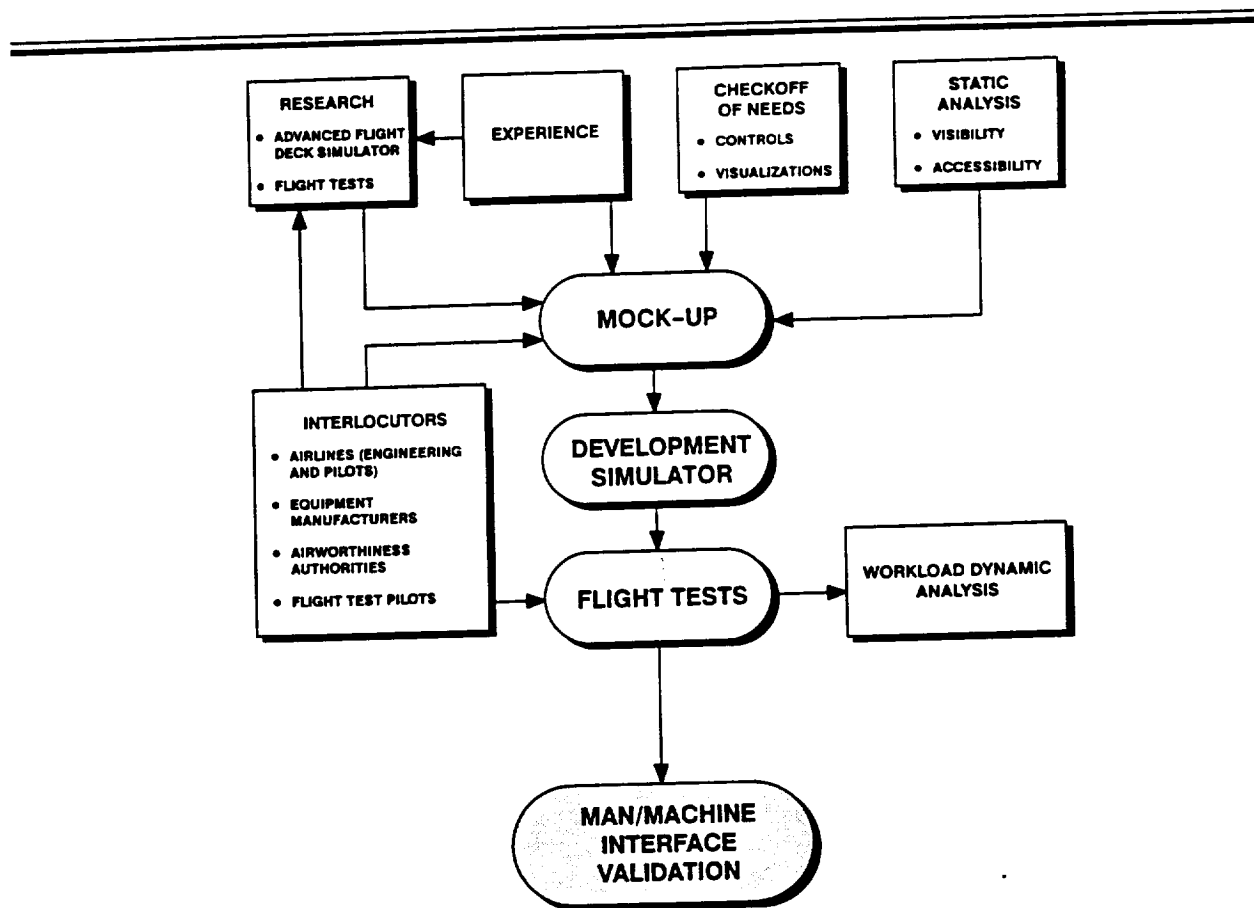


Figure 2.4-6. Cockpit Development Methodology

copilot's station, an LCD repeat of the pilot's CRT attitude directional indicator. The symbology on the LCD was provided by a silicon graphics symbol generator. The contrast of the LCD was poor, with an overall amber tint to the display. When queried regarding the fidelity of the display, and to all other questions regarding the display, host personnel simply reported that the requested information was proprietary.

Other recent research by Aerospatiale includes studies on 3-D visualization, flat panel implementation, voice control, touch control panels, and advanced ground collision avoidance systems (GCASs). The GCAS study involved the investigation of a potential terrain-collision-and-avoidance display. This CRT display presents a graphic (animated) representation of a land scene from an

established database. Ground lower than the aircraft's current altitude is presented in green, indicating that there is no threat of collision in these areas. Ground higher than the aircraft's current flying altitude (such as mountains) is represented in red, indicating the presence of a collision threat.

2.5 AUTOMATED DESIGN AND SOFTWARE ENGINEERING

2.5.1 Overview

The European avionics community has a number of well-thought-out, comprehensive programs in place to develop advanced automated design and software engineering technologies.

Following are European trends in automated design and software engineering:

- More efficient and faster techniques for developing avionics software specifications;
- More efficient techniques to develop the software itself through system workshops and other means as illustrated in Figure 2.5-1;
- Improved techniques for the development of error-free software through the use of independent software panels in the original development of the software and in its validation and verification;
- Automation in aircraft monitoring and maintenance;
- Computer-aided system specification tools;
- Improved use of software configuration control tools;
- Use of computer-aided software engineering (CASE) to the full extent allowable by the current and emerging state of the art;
- Software integration and validation tools to confirm that new software is error-free and conforms to the avionics software design specifications;
- Use of knowledge-based systems for appropriate applications;
- Automation of comprehensive aircraft monitoring systems, including engine monitoring, structural monitoring, etc.;
- Treatment of software like hardware, with part numbers; and

- Accelerating the process of avionics software specification, development, and validation through software system workshops.

2.5.2 Program Specifics

Certain critical algorithms in software development are being subjected to formal design and proof methodologies.

Software testing can demonstrate only the presence of errors, never their absence. Even after a program appears fully debugged, new inputs may cause it to fail. As a result, some elements of the European avionics community are trying to develop complementary alternatives to testing. GEC Avionics and some other European companies want to verify software correctness through the application of mathematical principles. Some success has been realized in this regard with small programs, but not with large, complex, fully functional systems-level programs. As computer programs grow in size, the length of time required for the mathematical verification becomes unmanageable, often resulting in a verification program that is as long as the avionics system software program itself and as error-prone. To verify large programs, the mathematicians and computer scientists working in these areas will need to "increase our powers of reasoning by an order of magnitude." This is a quite ambitious, and perhaps, unrealistic goal that the European avionics community is pursuing.

New and improved software design tools, as commercially offered proprietary products, are continuously being delivered to the European market by such companies as Sextant Avionique and GEC Avionics. However, within the Airbus community, many individuals believe that avionics system networking and software, as a continually evolving technology, provides ample opportunity for problems to arise. The recognized problem of mating data with software in a number of commer-

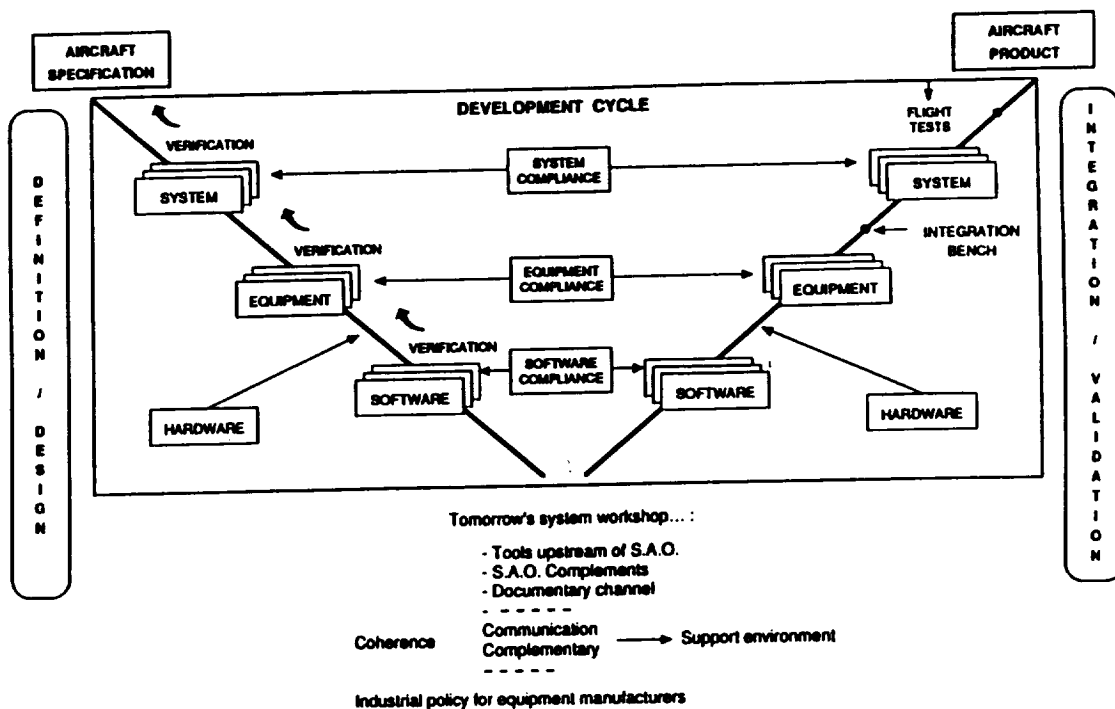


Figure 2.5-1. System Workshop Process

cial aircraft systems is one that the European community is attempting to address. For example, an "engine expert system" cannot yet determine exactly what maintenance should follow as the result of a data sequence. Improved software engineering should be able to determine necessary courses of action.

Currently, all European commercial aircraft software has been written to satisfy DO 178A Level 1 (flight critical) requirements. The European community is awaiting the next-generation RTCA standards to produce the next generation of needed software products.

Flexibility in software and configuration control for an ACMS, as far as commercial aircraft customers are concerned, is a key area of software

engineering. The view in the Airbus community is that customers should generally conform to standards in ARMS/ACMS. Otherwise, it becomes necessary to acquire different software for the different systems checks. If this needs to be done, the costs would fall solely on the customer. Hence, it would seem advisable for the customer to adhere to the standards of the ARMS/ACMS to save both time and money.

The European community has essentially standardized the practice of relying on independent software panels to design triple-redundant systems, such as flight controls, to reduce the probability of simultaneous/equivalent errors in a particular system. To guard against residual software errors, extensive verification and validation of the software is conducted by entirely independent panels, some-

times located in different geographic locations. Some companies, such as GEC Avionics, are attempting to implement formal mathematical design and proof methodologies to detect and/or reduce programming errors, as shown in Figure 2.5-2. As shown in Table 2.5-1, technological advances by Aerospatiale are reducing the debugging effort needed to produce operational software. Plans are being made for future software systems workshops on the definition, development, and validation of complete avionics systems software.

In all cases where presentations were made to the NASA review panel in the areas of automation and software, the European community was advancing the state of the art. Their automation and software programs can be expected to achieve at least modest success or, in some cases, significant or substantive success. In general, however, information on specific programs currently under way at the individual European companies was not released.

Table 2.5-1. Advances in Software Engineering

AIRCRAFT	A310	A320	A340
Number of different and redundant items of digital equipment	$53 + 24 = 77$	$56 + 46 = 102$	$67 + 48 = 115$
Volume of on-board software in MB	4	10	15 to 20
Equipment under AS responsibility	$47 + 23 = 70$	$38 + 37 = 75$	$48 + 39 = 87$
Volume in MB	3.8	9	13 to 18
Necessary debugging actions per 100 kB software	several hundred	several dozen	zero to less than 10

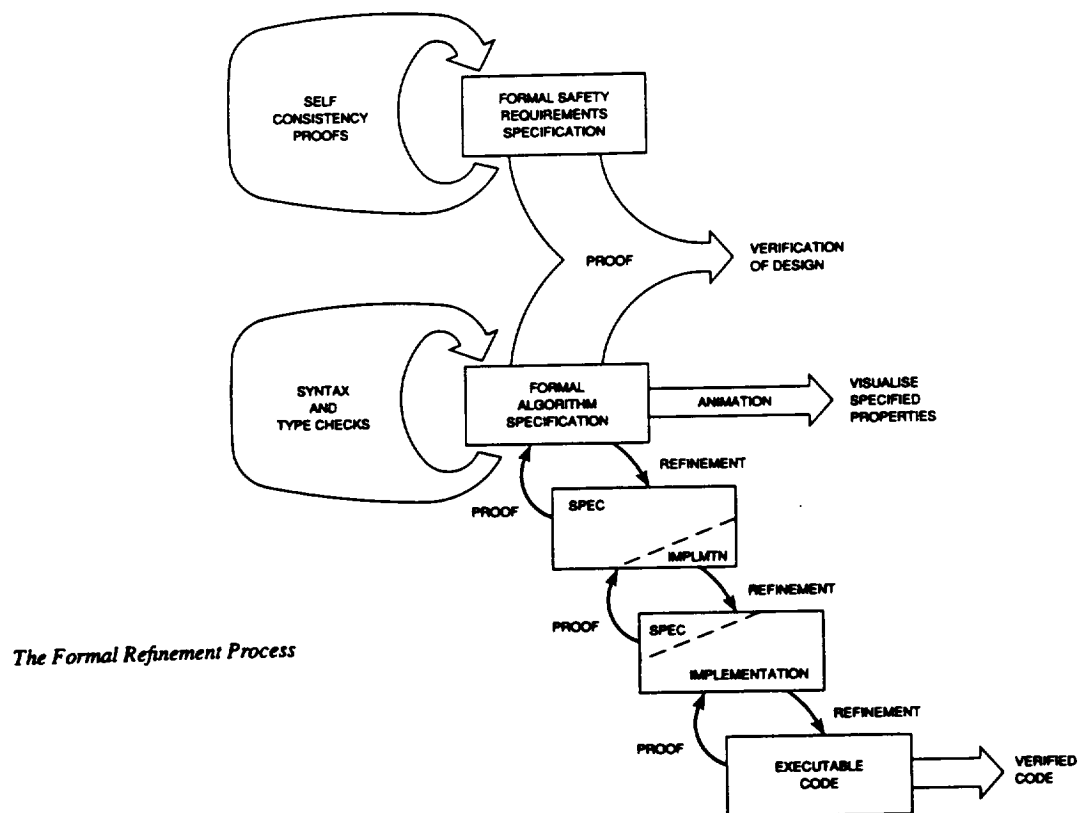
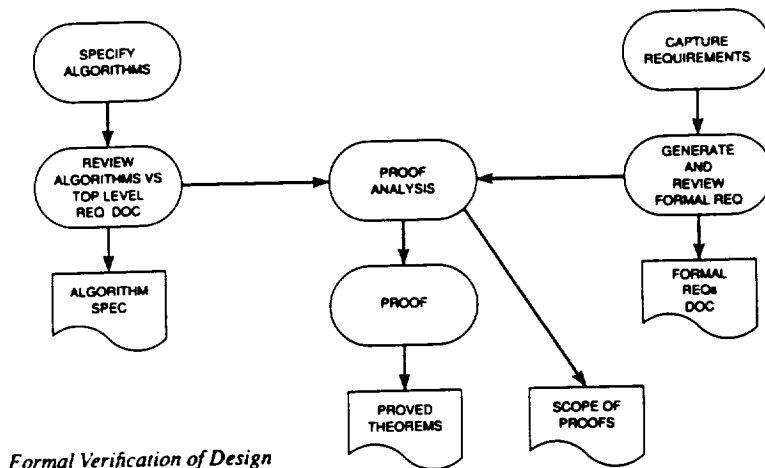


Figure 2.5-2. GEC Avionics' Formal Mathematical Design and Proof Methodologies

SUPPORTING RESEARCH AND TECHNOLOGY

Certain areas of technology, though not considered avionics by themselves, are integral parts of avionics systems and/or part of system interconnection. This section addresses technological advances in these areas.

3.1 OPTOELECTRONICS AND PHOTONIC R&D

The European community is pursuing the research and development of photonic and optoelectronic parts for use in highly structured avionics equipment.

3.1.1 Overview

A number of European companies have undertaken research on using optics technology for control and health-monitoring of flight and propulsion systems, on using fiber-optics technology for communication, passive optical sensors for measurements, and photonics for optical computing. Although no one has optical systems in production aircraft, a number of companies visited are engaged in research in the areas of optical sensors, photonics, and optoelectronics. At this time, the effort is relatively low-level.

The main stumbling blocks in transitioning the technology to production systems are the lack of credible data to substantiate the reliability of the technology in the aircraft environment, problems with production techniques, and the integrity of fibers and other components in a relatively robust maintenance environment. A number of demonstration programs have been completed, including fiber-optic datalink installations in helicopters and large commercial aircraft. The primary interest in

optics, at least for the present, concerns its potential advantages for flight control and data bus architectures relative to conventional systems in terms of:

- High certification costs,
- Complex wiring interconnections,
- Weight of harnesses, and
- Susceptibility to electromagnetic interference of wire systems.

An additional reason given by one company was the ability to use dissimilar technologies (optical and electrical) for improving reliability.

3.1.2 Program Specifics

The Optics and Laser Technology Department of British Aerospace's Sowerby Research Centre is developing electro-optical sensors, optical information processing techniques, gas-discharge lasers, improved laser systems, and pulsed power systems. The programs of greatest significance now under way at Sowerby Research Centre are Holographic Interconnects for Parallel Processing Systems and Optically Connected Parallel Machines (OCPM).

The OCPM project is a collaborative effort within the European community. Partners include British Aerospace, BNR Europe, Meiko, Heriot-Watt University, and Bath University. The program is proposed for a duration of five years, of which, funding for the first three years has been approved.

The objective of the OCPM project is to develop electronically controlled, free-space optical systems capable of interconnecting large numbers of advanced electronic processors and arbitrarily switching high-bandwidth signals between them.

The interconnect system will consist of an electronically addressed spatial light modulator (EASLM) positioned at the center of a single-stage optical crossbar configuration formed with holographic and bulk optical elements. Research during the first three years will investigate low setup latency and the possibility of connecting large arrays of processors and will include a demonstration using current EASLM technology. The remaining two years will focus on the production of a high-connectivity, low-latency, high-bandwidth communications system with 64×64 links, 5-10 μ sec latency, and approximately 500 Mb/sec. The system will incorporate the EASLM that was developed during the first three years. A block diagram of the OCPM system is illustrated in Figure 3.1-1.

Separately, electro-optical sensors are being developed for examining coherence properties of light as a means of improving discrimination. A

multi-band infrared radiometer has already been designed and assembled for use on a satellite.

Holographic Interconnects for Parallel Processing Systems (HIPPS) is a program funded, in part, by the Optoelectronics Programme of the LINK Initiative of Great Britain's Department of Trade and Industry and the Science and Engineering Research Council. It is a three-year project of British Aerospace (Sowerby Research Centre), Kings College, Pilkington (Group Research Centre), and Rutherford-Appleton Laboratories.

The aim of this program is to develop and evaluate advanced computer-generated holograms (CGHs) for use in highly parallel processing systems. Also, the program will experimentally evaluate both reconfigurable and fixed parallel processing systems. British Aerospace and Pilkington will continue to evaluate the use of electron-

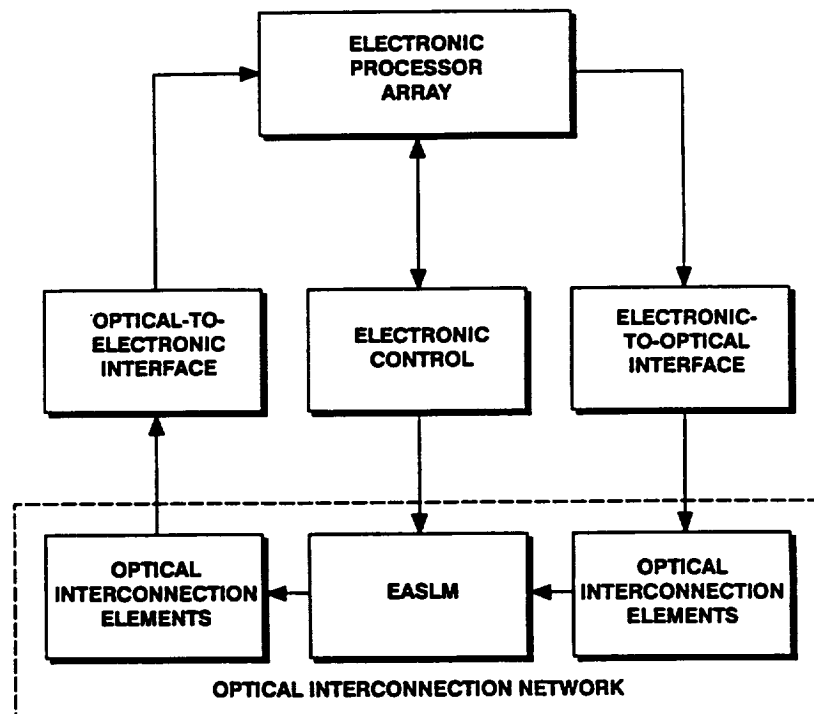


Figure 3.1-1. OCPM Block Diagram

beam lithographics for CGH fabrication for HIPPS. If incorporated, this technique should allow for the production of very-high-resolution holograms. CGH technology is intended to provide a means for forming the high-density interconnects necessary for highly parallel processing systems.

The Optical Information Processing Program, conducted at Sowerby, studies the use of direct optical processing for image analysis and recognition. Fundamental research is under way for the development of optical interconnects for computing and communications. This involves the design and evaluation of experimental demonstrators that incorporate holographic techniques and spatial light modulators. Of particular interest for the implementation of these optical processing methods are highly parallel architectures such as neural networks requiring a large degree of connectivity. In addition, research is being done on optical data-fusion and knowledge-based systems as well as advanced information processing that uses optical processing techniques, artificial intelligence, pattern recognition, and computer vision architecture.

Sowerby's Optics and Laser Technology Department (OLTD) is concentrating on the R&D of pulsed, transversely excited gas discharge lasers with improved performance in terms of beam quality, power, repetition rate, and reliability.

OLTD is also developing improved laser systems for communications and guidance applications. Military systems have already been developed for these purposes. OLTD's research involves visible systems as well as $1\ \mu\text{m}$ and $10\ \mu\text{m}$ infrared systems. Specific efforts include:

- Pulsed power systems for driving pulsed gas lasers,
- Application of magnetic materials to pulsed power generation (magnetic

switching and magnetic pulse compression), and

- The use of bi-stable and multi-stable interferometers as switches to optically transmit and receive with sensors and actuators.

Sowerby Research Centre's Material Science Department is investigating the interaction of laser light with various materials as a function of fluency and wavelength. In addition, Sowerby is developing improved spatial light modulators for use in optical processing, computing, and simulators. The performance of these devices is linked to improvements in photoconductor, liquid-crystal, thin-film, and micro-machining technologies.

The primary focus of the GEC Avionics Technology and Systems Research Laboratory (TSRL) is the design of advanced HUDs. The results of this effort have been applied to the optimization of the HUD optics in the EFA. TSRL is also designing advanced systems that might be used to replace CRTs. Improved LCDs might also have applications in optical switching.

As part of their research effort, TSRL employs a very comprehensive software package that is capable of ray-tracing extremely complex optical devices, including holographic lenses and computer-generated holograms.

ONERA is working with holographic imaging for 3-D radar imaging applications. ONERA uses an infrared camera for infrared thermography to measure model heating during wind tunnel tests. Experiments to evaluate laser-matter interaction are being conducted. ONERA has designed and developed a range-finding camera called TILT, which uses a 3-D laser imaging technique to accurately image the near-space forward of the vehicle.

ONERA is also conducting research in:

- Instrumentation, using an electron gun to excite fluorescence centers to determine vibrational and rotational temperatures in airflow.
- Adaptive optics for high-resolution imaging by correcting distortions created by atmospheric turbulence. The ONERA optical system contains a deformable mirror, the surface of which is actively modified to compensate for atmospheric aberrations.
- Optical visualization and diagnostic techniques to analyze turbulent flow using 2-D Fourier transformation of Schlieren images.
- Infrared techniques for the computation of infrared signatures of aircraft plumes observed from the atmosphere.
- Quantum optics.
- Laser-induced fluorescence studies of excited oxygen.

DLR is researching fiber-optic sensors and optical components. Interferometric strain gauges using optical fibers will be installed on test-bed aircraft to evaluate the concept of "smart skin" aircraft; these gauges will be able to measure strain in aircraft structures, and the measurements can possibly be used to predict when cracks will start to develop in the structure. The use of optical fiber-laced composite structures is being studied with preliminary flight tests of a simple optical fiber pasted to a test-bed aircraft wing.

Smiths Industries' Putney plant researches and manufactures igniters, optical sensors, pyro-

metry, and thermocouples. The plant is also working on optical high-temperature sensors and rotary position wavelength division multiplexed (WDM) sensors. Smiths Industries provides optical pyrometers for the Pegasus engine, although this system uses electronic data transmission from the sensor to the control unit. Ongoing research efforts are being applied to the study of materials for the pyrometer's protective sheeting that covers the sapphire rod on which the black-body material is mounted. Smiths Industries has developed a proprietary method to attach platinum to the sapphire rod. The sensor has experienced over 500 cycles in a flowing hot gas stream with minimal damage to the tip. A rotary optical sensor operating on the WDM principle with a triple-sensing head is being evaluated for Boeing for possible use on their B-777 aircraft.

Part of Smiths Industries' research is in the design of optical systems to replace the connector interface of the full-authority digital engine control (FADEC). According to Smiths Industries, virtually all the problems with FADEC can be traced to the interface box. Optical systems would simplify the connector interface. The company's design philosophy for constructing the control box and connector interface is one of versatility and expansion. As the system grows and additional boards are required, they can be added without replacing the control box, saving both time and money. Smiths Industries is evaluating a proposal for running raw power to the actuators and for controlling the flow of electrical energy to the actuator with optical signals. They are working on the use of gallium arsenide (GaAs) for the high-temperature electronic capability.

Smiths Industries is ready to demonstrate an optical fuel-gauging system. They currently have acoustic fuel-gauging systems flying in parallel with the standard capacitance fuel-gauging systems. The

fuel management system uses a unique signal bus cross-over technique in which the separate channels from fuel-level sensors enter the box at the connectors, cross over to the next section of electronics, and then cross over again as the signal lines exit the components.

Smiths Industries is conducting long-term research to develop optical sensing and multiplexing techniques. Coherent multiplexing is based on interferometric principles and requires single-mode optical data buses. The research goal is the development of an optical ARINC 629 bus architecture. Their long-term program will include optical back-plane research.

The major optical technology being pursued at Aerospatiale is FBL systems. Aerospatiale currently has two programs dedicated to the R&D of FBL technology. These programs are:

- CLOVIS I - To evaluate the performance of basic optical components in a real environment.
- CLOVIS II - To research new generations of passive components and optical position sensors.

A laboratory mock-up of an emergency FBL control mode is shown in Figure 3.1-2.

Aerospatiale has also developed a modular approach to the installation of fiber-optic components. As shown in Figure 3.1-3, their approach connects the active components (transmitter and receiver) by optical fibers and passive component modules.

3.2 TRAINING AND SIMULATION SYSTEMS

3.2.1 Overview

European R&D in the area of training and simulation systems is centered at two companies, the DLR Institute for Flight Guidance and Aero-spatiale.

DLR is involved in two main R&D programs, the German Cooperative Air Traffic Management Concept (CATMAC) and the joint European Program for Harmonized Air Traffic Management Research in Eurocontrol (PHARE). Technology areas encompassed by these programs include experimental flight management systems and common module simulators. Other major efforts under way at DLR include advanced technology testing aircraft systems (ATTAS) and taxi and ramp management control (TARMAC).

Aerospatiale's main programs are the Investigation of the Ergonomics of the Piloting Station (EPOPEE III) and Future Air Traffic Control (ATC) New System and Technology Impact on the Cockpit (FANSTIC). These programs include the Traffic Collision and Avoidance System II (TCAS II), 3-D visualization, flat panel implementation (FPD/ND, standby instrument), voice control concepts (direct voice input/direct voice output), touch control panel, and ground collision avoidance systems (GCAS).

3.2.2 Program Specifics

The two programs with major DLR participation refer to advanced integrated air/ground traffic management concepts including new onboard equipment and new ground-based CNS technology and use of datalinks. The first program, CATMAC, should be implemented by the late 1990s. The objective of PHARE is to demonstrate the merits

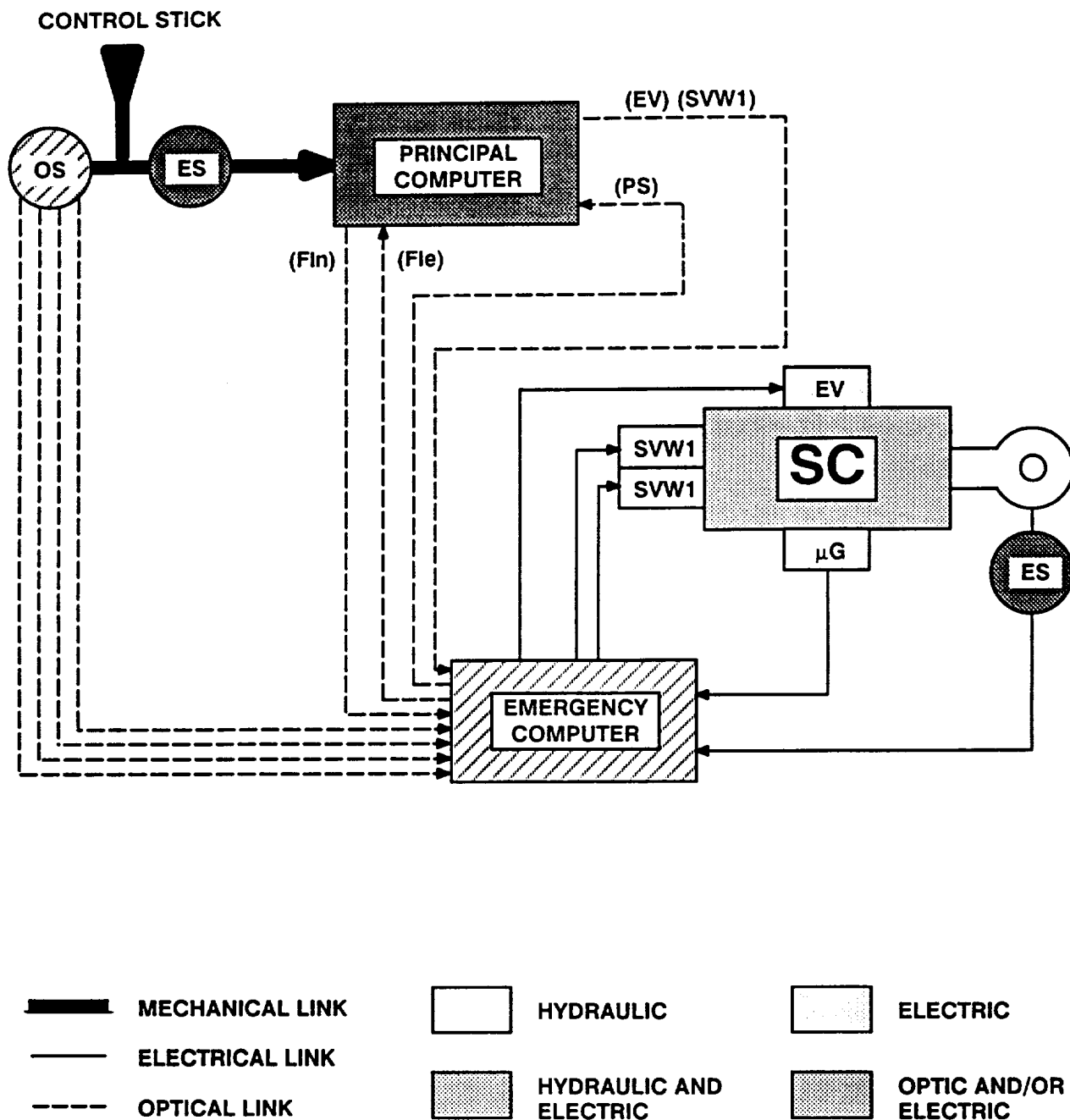


Figure 3.1-2. Laboratory Mock-Up of an Emergency Fly-by-Light Control Mode

MODULARITY APPROACH

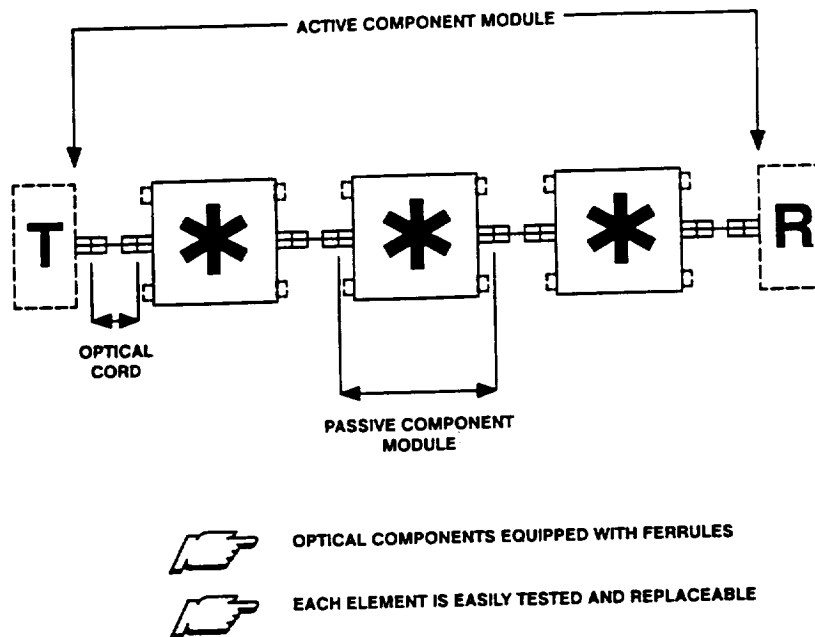


Figure 3.1-3. Installation of Fiber-Optic Components

and prove the feasibility of future air/ground integrated air traffic management (ATM) systems, which will resolve issues such as the need for increased capacity. The PHARE program will include an experimental flight management system (EFMS) and a common modular simulator (CMS), an experimental aeronautical telecommunication network and so-called advanced tools.

The objective of EFMS is the development of an experimental facility to be integrated in either a real test aircraft or a ground simulation environment. Novel functions of the EFMS include determination of near-optimum climb, cruise, and descent trajectories and consideration of multiple constraints, including restrictions on the route of flight, altitude restrictions, airspeed, and arrival time at various way-points.

DLR's ATTAS is used in flight simulations, pilot-in-the-loop experiments, software tests, and

other functions. There are no space constraints that limit the amount of equipment integration possible with ATTAS. The experimental cockpit includes several (approximate) 5 in. x 5 in. CRT displays, as in the Airbus A310. The ATTAS aircraft has a direct lift control surface, weighs 46,000 lbs, has a FBW cockpit, and has flown a total of 2,000 hrs. It was built in 1974 and was reconfigured for experimental purposes three years later.

DLR's TARMAC project uses simulation as one of its main development building blocks. TARMAC's main functions demonstration is expected in the fall of 1992.

TARMAC will provide for several basic needs of a future system, including:

- An improved surveillance and identifying capability;

-
-
- An improved planning and control capability
 - More efficient methods for controller-pilot communication; and
 - Improved, precise, and unambiguous taxi-guidance information to pilots.

TARMAC will provide several functions either automatically or with controller interaction, such as:

- Traffic situation display for controllers using a 20 in. x 20 in. raster-scan display;
- Optimum conflict-free taxi route advisories,
- Optimum taxi schedule advisories;
- Optimum start-up sequence and schedule advisories;
- Optimum pushback sequence and schedule advisories;
- Taxi route monitoring and alert;
- Intersection and taxiway conflict alert and priority advisories;
- Clearance limit and area violations, monitoring, and alert;
- Facilities operational status monitoring and display; and
- Digital data output, datalink, and message transmission to the pilot, cockpit, flight management system and automated surface guidance equipment.

Aerospatiale's cockpit development methodology is critically dependent upon its advanced flight deck simulators, mock-ups, and developmental simulators. Aerospatiale's EPOPEE III project of early 1984 through 1990 is one of their main research programs in cockpit development. EPOPEE III is a French national program with the Aerospatiale Technical Director serving as coordinator, and Aerospatiale Avionics and Systems Directorate, Sfena, Thomson-CSF, and Crouzet serving as partners in the program. The main lines of research of EPOPEE III involve the retrofit of a simulator with advanced organization of controls and displays and a new cockpit layout that includes new short-motion controls (e.g., side-stick controllers) and speed rate controls (e.g., throttle). Aerospatiale simulators have supported studies on 3-D visualization, the TCAS II alert display, flat panel implementation, voice controls using direct voice input and output, touch control panels, and ground collision avoidance system.

Like all Aerospatiale advanced cockpit studies that involve simulation systems and the MMI, EPOPEE III is headed by Marie-Claude Pomery. The fixed-base simulator used for EPOPEE III employs an all-glass cockpit configuration similar to the A320 and A321 aircraft. Madam Pomery has noted that investigations of EPOPEE III voice control applications have been inconclusive with regard to the usefulness of voice control. When touring the simulator, several NASA panel members noted that the voice control was very sensitive to individual speech patterns, accepting commands from just one or two of the Aerospatiale experimenters and only one of the NASA panel members, and then only when he adopted a thick French accent for stating his commands to the system.

The symbology of the TCAS II was different than the standard FAA symbology and combined the typical horizontal situation indicator and attitude

direction indicator. The touch control panel in the simulator functioned as a data-entry, direct-designation system that operates on the same principle as a computer mouse controller. The operator touches the screen once and, keeping his finger in contact with the panel, moves to his next choice on the screen.

Several other Aerospatiale cockpit research programs rely heavily on their advanced cockpit simulation systems. Aerospatiale's cockpit research program, which began in early 1990 and is planned for completion in early 1992, is known as Future Air Traffic Control New System and Technology Impact on the Cockpit. Aerospatiale is the coordinator for this multinational (European) cooperative effort. Partners in the program include aircraft and equipment manufacturers, research centers, and universities, for a total of 14 members from 8 different countries.

Overlapping the FANSTIC time frame is Aerospatiale's Programme de Recherche sur l'Environnement Futur des Avions Civils et leurs Equipements (PREFACE). PREFACE is a French national program with Aerospatiale serving as coordinator and Sextant Avionique and DGAC (CENA) serving as partners. PREFACE began in late 1990 and will continue until mid-1995. Phase I will use Aerospatiale cockpit simulation systems to determine human operator capability and to produce a weakness assessment. Making special note of Aerospatiale's efforts to include sound human factors principles from the very start of their research, Madam Pomery further explained that program goals would be accomplished by setting up an incident/accident database consisting of both European and U.S. data, implementing a theoretical study on pilot behavior, and following that with an experimental study. PREFACE/FANSTIC will also determine the impact on flight deck and operational systems of future air transport environments,

including general systems evolution such as: MLS, TCAS III, ACARS, SATCOM, and datalink ATC.

Three areas remain to be investigated in the second half of PREFACE/FANSTIC Phase I. The first involves a study on an electronic library system (ELS) fully integrated into the avionics and the cockpit to produce a paper-free cockpit. The second area of future research involves the evaluation of newer technologies for the cockpit, including full implementation of LCDs and optical mass memory. The third and final line of research for PREFACE/FANSTIC Phase I will use the results of the previous research plus any newly available technologies to design and implement new and improved controls and displays in the research simulator.

Aerospatiale's PREFACE/FANSTIC Phase II research projects will continue until at least 1997. This phase of PREFACE/FANSTIC will use advanced cockpit research simulators to acquire new information in four major areas:

- **Human Factors.** Aerospatiale plans to set up simulated scenarios of past accidents, using data extracted from the aforementioned multinational accident data base. Pilot reactions under identical (but simulated) circumstances identical to the original incident/accident will be analyzed. If the pilot reactions in the simulated scenario are, in general, similar to that of the pilot during the actual accident, further research will be conducted to determine what changes in the system are necessary to reduce or eliminate the chances for any further incidents/accidents of that type.
- **New Technology.** The second area of Phase II research will consider the impact of new technology on areas such as visualization, voice control, and designation systems.

-
- Ground/air cooperation and communications networks.
 - New systems such as taxi guidance, takeoff monitoring systems, and wind-shear prediction systems. Aerospatiale envisions one day being able to predict windshear conditions. In anticipation of this technology, the advanced cockpit research simulators will be used to aid in the development of appropriate pilot advisories under wind-shear conditions, such as a suggested angle of attack.

Aerospatiale is definitely a world leader in cockpit MMIs and associated simulation technologies. Aerospatiale did not discuss whether it employs its simulators for pilot training.

British companies are very active in avionics product research, development, and manufacture. Although no significant information was provided on training and simulation systems or ongoing programs, it can be assumed these companies employ research simulators for their controls, displays, and human factors research.

British Aerospace uses both real aircraft flight deck simulators and laboratory mock-up simulators in their R&D efforts. Previous British Aerospace advanced flight deck simulators have been among the first "glass cockpit" simulators.

Sowerby Research Centre is home of the British Aerospace human factors department and its Vertical Launch Seawolf Break-Up Operator Simulator. Although detailed information is not available, it is highly probable that the Human Factors Department employs several different types of cockpit mock-up research simulators for R&D purposes.

Other European companies have also touched on the R&D of trainers and simulation systems. Sextant Avionique's highly active MMI technology research requires the use of research simulators. However, no information regarding Sextant Avionique research simulators was provided to the NASA panel. It is possible that Sextant Avionique may work with other French companies such as Aerospatiale in addition to or instead of using in-house simulators. A precedent for this is seen in the aforementioned PREFACE program in which Aerospatiale serves as the coordinator and Sextant Avionique as a partner.

APPENDIX A1

SITE REPORTS

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1.0 Date of Visit: 14 June 1991

2.0 Panel Members:

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Cary Spitzer
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Alan Angleman

3.0 Principal Contacts at Facility:

Helmut Kalbe	Avionic Systems Design
Michael Schwenke	Avionic Systems Design

4.0 Facility Overview and Organization

Deutsche Airbus and its previous lineage represent a significant, historically prominent facet of German/European success in the fields of aerospace design, research and development, testing, and production. In conjunction with the European Airbus Industries consortium and other related companies, Deutsche Airbus has participated in many significant historical developments, and it has achieved considerable current attention for its contributions to Airbus aircraft. The organization of Deutsche Airbus GmbH reflects its multi-faceted lineage and the charter the company adopted to become a leader in international aerospace programs. Many of the most important names and firms of German aeronautical history, reaching as far back as the early 1900s, may be found in the Deutsche Airbus family tree (Figure A.1-1).

During the reorganization of the German aircraft and aerospace industry in the late 1980s, Deutsche Airbus was founded as part of the Deutsche Aerospace Company. The German government provided this new organization with a nominal capital funding of 930 million Deutsche Marks (DMs) (approximately 500-600 million 1991 U.S. dollars). This funding of Deutsche Airbus GmbH was underwritten by Messerschmitt-Bölkow-Blohm GmbH (80%) and Kreditanstalt für Wiederaufbau-German federal government (20%). In 1989, Deutsche Airbus achieved sales of 3.5 billion DM.

Currently, Deutsche Aerospace constitutes 20% of Airbus Industries, a European aircraft consortium. Its 20% share compares with that of Aerospatiale (37.9%), British Aerospace (37.9%), and CASA-Spain (4.2%). The consortium's main product is the Airbus family of wide-body aircraft comprising the A300, A310, A330, and A340 as well as the smaller A320 and A321 aircraft.

The integration of Deutsche Airbus with Daimler-Benz, a leading high-technology concern, and component suppliers such as Dornier and CASA (Spain) establish the company as a well-founded, highly competitive vehicle for the most ambitious aerospace programs of the future.

The core of Deutsche Airbus GmbH, located in Northern Germany, comprises six facilities that were formerly part of the MBB Transport Aircraft Group. The buildings, equipment, laboratories, and other fixed assets are classified by Deutsche Airbus as modern or ultra-modern. These six plants all contain computer support, telecommunications, test facilities, research laboratories, and airfields. Each of the plant's employees and functions are thoroughly specialized and performance-optimized, with the work flow centrally controlled and computer-coordinated. The six facilities are located at:

- Hamburg (Company Headquarters)
- Bremen
- Einswarden
- Varel
- Stade
- Lemwerder (Aircraft Service Center)

The plants at Bremen and Varel specialize in sheet metal component manufacture and component machining, respectively. They, in turn, provide the supplies for fuselage shell manufacture in Einswarden. The Einswarden plant, together with the plastics processing center in Stade, supplies the fuselage assembly operation at the Hamburg plant. After aircraft final assembly in Toulouse, France, by other consortium members, Airbus aircraft are flown back to Hamburg for cabin furnishing. Finally, the Aircraft Service Center in Lemwerder maintains and services aircraft of various makes. Deutsche Airbus headquarters in Hamburg oversees the centralized data processing that coordinates

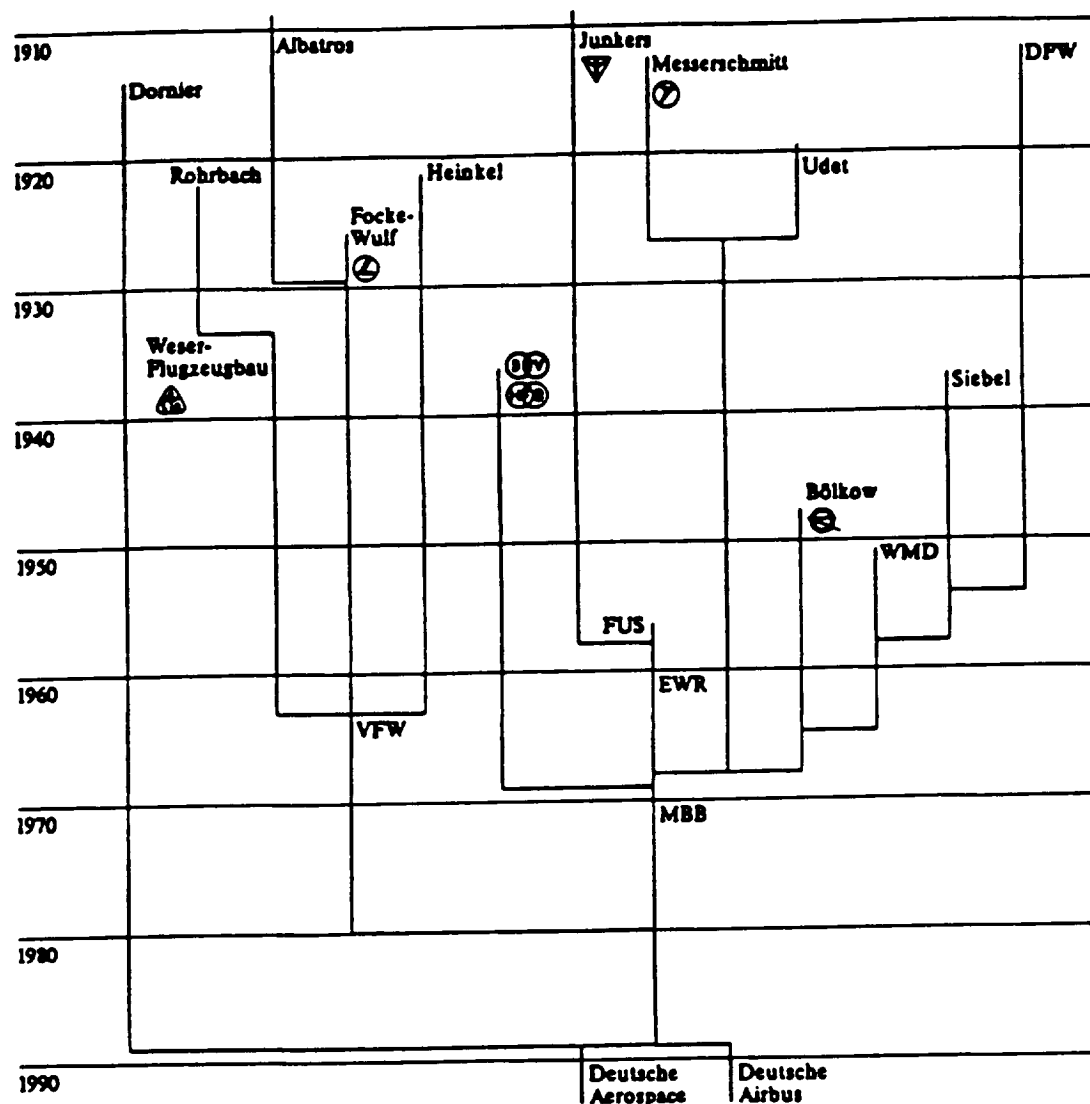


Figure A.1-1. Deutsche Airbus Company Lineage

manufacturing activities at the different plant locations.

The Hamburg plant offers a comprehensive range of direct customer-related services for wide- and narrow-body aircraft, as well as military transport aircraft, including:

- Maintenance and support
- Repair and modification
- Painting
- Cabin renewal
- Storage and care

With 7,000 employees, 4,000 in the manufacturing department alone, the Hamburg plant encompasses approximately 1.3 million m² of space. Of this, 228,300 m² is used as a production assembly building and hangar space. The Hamburg plant also boasts a 1,928 m runway which will be extended to approximately 2,400 m.

The Aircraft Service Center is located at the Lemwerder plant. Lemwerder holds licenses from all major airworthiness authorities world-wide to operate as a maintenance and service center. With a 1,900 m runway and 1,300 employees, Lemwerder has sufficient space, facilities, and manpower to support customer needs for a wide variety of aircraft services.

The Einswarden plant is the fuselage shell manufacturing center of Deutsche Airbus. Operations concentrate on producing structures for commercial aircraft through the combination of fuselage shells with machined components from Varel and sheet metal components from Bremen. The production area is approximately 90,000 m², encompassing 18% of Einswarden's 500,000 m² ground area. Its manufacturing capacity totals approximately 2 million man-hours annually with 2,200 plant employees.

The Stade plant is the manufacturing center for reinforced plastic components. It is at this facility that various advanced technology composite materials are incorporated for their reinforcing capabilities. These components are used to produce complete Airbus Industries aircraft parts, including: vertical fins, spoilers, air brakes, landing flaps, and surfaces such as covers and plates. The facilities constitute 150,000 m² ground area and 1,400 employees. The production area covers approximately 38,000 m².

The Bremen plant of Deutsche Airbus is second in size to Hamburg with a total ground area of 447,000 m² and a payroll of 3,700 employees. Production takes up 32% of the facility space, approximately 144,000 m², and constitutes 49% of the entire facility's work force. The remaining 1,900 employees provide development and central administrative support.

The Varel plant principally manufactures technical components for commercial aviation, mainly for the Airbus program. According to Deutsche Airbus, Varel has consistently attained extremely high levels of precision and reliability through the application of a computerized machine tool database system that was developed in-house. The Varel plant has grounds that cover 130,000 m² with 40,000 m² allocated to building space. The Varel plant employs over 1,400 people and attains an annual manufacturing capacity of slightly over one million man-hours.

5.0 Avionics R&D Programs

Deutsche Airbus has performed critical analysis and development of numerous systems and components for the Airbus family of aircraft. Some of the past, current, and planned Airbus production aircraft on which Deutsche Airbus has worked include:

-
-
- A300, A300-600 with 267 seats and a range of 8,000 km.
 - A320, with 150 seats and a range of 5,500 km.
 - A321, the stretch version of the A320 with 180 seats.
 - A330, a 328-passenger twin-jet with a range of 9,000 km.
 - A340, a four-jet, long-range aircraft with 262-295 seats and a range of 12,300 and 13,800 km.

Other projects to which Deutsche Airbus has contributed include:

- Fokker 100, a twin-jet with a 2,200 km range.
- Fokker 50, a 50-seat turboprop.
- MPC 75, a twin-jet regional passenger aircraft (pre-development activities in cooperation with China).
- TRANSALL C-160, a multi-role transport aircraft.
- EROFLAG, a European definition project for the successor to the Hercules/TRANSALL.
- HFB 320, independent effort for the first German business jet.
- VFW 614, currently on duty with Special Air Mission Unit of the German federal government and in use as a flying test bed (ATTAS).

5.1 The Aircraft Recording and Monitoring System Project

The Aircraft Recording and Monitoring System (ARMS) contains the Digital Flight Data Recording System (DFDRS) and the Aircraft Condition Monitoring System (ACMS). The DFDRS is used for mandatory recording to fulfill airworthiness requirements. The ACMS is a customer-requested item used for aircraft condition monitoring to support long-term aircraft/engine maintenance. The current goal of the ARMS program is to improve upon the DFDRS and the ACMS. Deutsche Airbus is the direct sponsor of this program. Work on the program is organized under the Avionics Systems Design section of Deutsche Airbus. It appears that the ARMS will be ready and offered for use on the coming A330 and A340 aircraft.

The introduction of improved DFDRSs and ACMSs has been accelerating in recent years. In addition to the use of these systems for obtaining enhanced incident-related information, they are frequently incorporated into the development of improved training programs, flight operational procedures, and aircrew/aircraft monitoring. A great deal has been written and discussed on the subject of improved DFDRSs and ACMSs. The description of recent work contained in References 3, 34, and 36 provides a good account of improvement, use, and trends related to past, present, and future research, development, and engineering efforts.

The main function of the DFDRS is to record 414 numeric and discrete parameters in a crash-protected solid-state flight data recorder. The recorded information is organized into four 128-word (12-bit) subframes to fulfill the requirements set forth by the airworthiness authorities. The minimum recording time capacity is 25 hrs. Through the use of adequate pin coding, 64-word

subframes make it possible to feed old flight data recorders.

The Deutsche Airbus A330/A340 ARMS principal block diagram of the DFDRS and ACMS is shown in Figure A.1-2. Note the use of the ARINC 429 data buses. So far, all Airbus inputs are ARINC 429 compatible. Switching to the technology necessary to use ARINC 629 data buses appears to, at this time, cause Deutsche Airbus some concern about cost and patents. The flight data information unit (FDIU), which acquires and analyzes the data, and the flight data recorder (FDR) are both flight-critical components. If either the FDIU or the FDR fails, the aircraft can only be flown to a maintenance depot or base until repairs are made.

The data management unit (DMU), including the smart ACMS recorder (SAR), is the heart of the ARMS (Figure A.1-2). It has a 3.5-MB memory with five channels and a 32-bit processor. The quick access recorder is linked to the FDIU for convenience but may be eliminated in updated designs. The DFDRS coding panel contains ARINC-type coded information such as tail identification number and engine type.

The centralized maintenance computer on board the aircraft is part of the centralized maintenance system and receives fault messages in clear English. The CMC has no analyzing capacity. The DMU represents the Aircraft Communications Addressing and Reporting System (ACARS) portion of the ARMS. The remaining units are the:

- Digital ACMS recorder
- Multi-purpose disk drive unit (MDDU)

- Multi-purpose control display units (MCDUs)
- Printer and select event/print panel

Figure A.1-2 illustrates the principal relationships of the ARMS with respect to other system elements.

The principal functions and attributes of the Deutsche Airbus ACMS are:

- Acquisition of 3,300 ARINC 429 data words
- Continuous monitoring of 312 numeric and 288 discrete parameters
- Parameter display on the MCDUs and display print
- Data recording with data compression in a solid-state mass memory (SAR)
- Generation of 18 standard print reports for various purposes, (e.g., engine condition monitoring)
- Free programmable DAR data, selection from received parameters
- Free programmable SAR data, selection from received parameters
- Transmission of print reports to ground via ACARS
- SAR data and report data dump on diskettes

The ACMS is capable of generating 18 different standard reports. Additional reports can be programmed with ground support equipment and

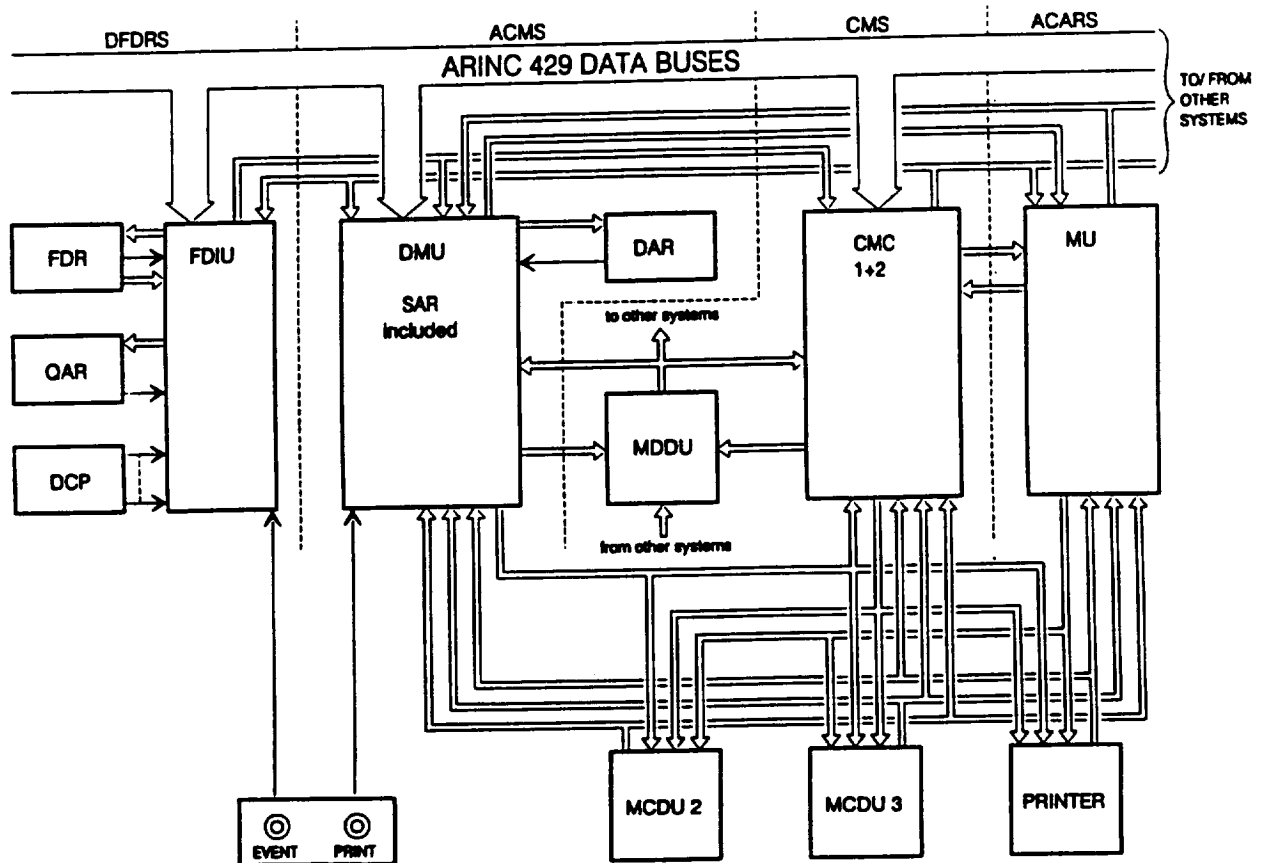


Figure A.1-2. A330/A340 ARMS Principal Block Diagram

implemented via the MDDU. The standard reports developed by the ACMS are:

Report 01-Engine Cruise—For engine condition monitoring and engine performance calculations; provides a "snapshot" average of 100 seconds of data on items such as thrust, exhaust gas temperature, different stage pressures, exhaust pressure ratio, and fuel flow.

Report 02-Cruise Performance—For aircraft performance calculations; similar to Report 01 except the averaging period is much longer.

Report 04-Engine Take-Off—For statistical evaluation of takeoff power and engine monitoring; provides data such as power level during takeoff and climb and the average maximum power level for all engines on the aircraft.

Report 05-Engine Report on Request—Manually initiated for engine event investigations; initiated by the flight crew to record a perceived situation.

Report 06-Engine Gas Path Advisory—Advisory report for exceedance evaluation of engine gas path parameters.

Report 07-Engine Mechanical Advisory—Advisory report for exceedance evaluation of engine mechanical parameters.

Report 09-Engine Divergence—For evaluation of engine short-time divergence; triggered by the exhaust gas temperature and nacelle temperature sensors; provides engine data that compares a few vital engine parameters with all the other engines under symmetrical power conditions; reports endurance of unusual situations.

Report 10-Engine Start—For evaluation of engine shutdown during engine start.

Report 11-Engine Run-Up—Manually initiated for monitoring of engine run-up.

Report 14-Auxiliary Power Unit (APU) and Main Engine Start/Idle—For APU monitoring and APU/main engine shutdown.

Report 15-Exceedance of Flight Loads—For evaluation of in-flight load exceedance and hard landing reports; G-load compensated for all aircraft flight path parameters.

Reports 16, 17, 18-Free Programmable—For special investigations; customer may select the parameters desired.

Report 19-Environmental Control Systems—For troubleshooting of the environmental control system (ECS).

Report 20-Ram Air Turbine Test—Initiated manually on the ground by the maintenance crew for ram air turbine testing only; used to request a maintenance data report with the MCDU.

Figure A.1-3 shows the consecutive screen displays of the MCDU. Figure A.1-4 shows the schematic for the ACMS ground interface.

A typical report readout is shown in Figure A.1-5. The top line is the title line, identifying the report as an A320 Engine Cruise Report 01. The next line defines the parameters to be used in the third line, labeled CC. The aircraft tail number identification is first, blacked out for this report, followed by the date, time (Universal Coordinated Time), departure airport, destination air

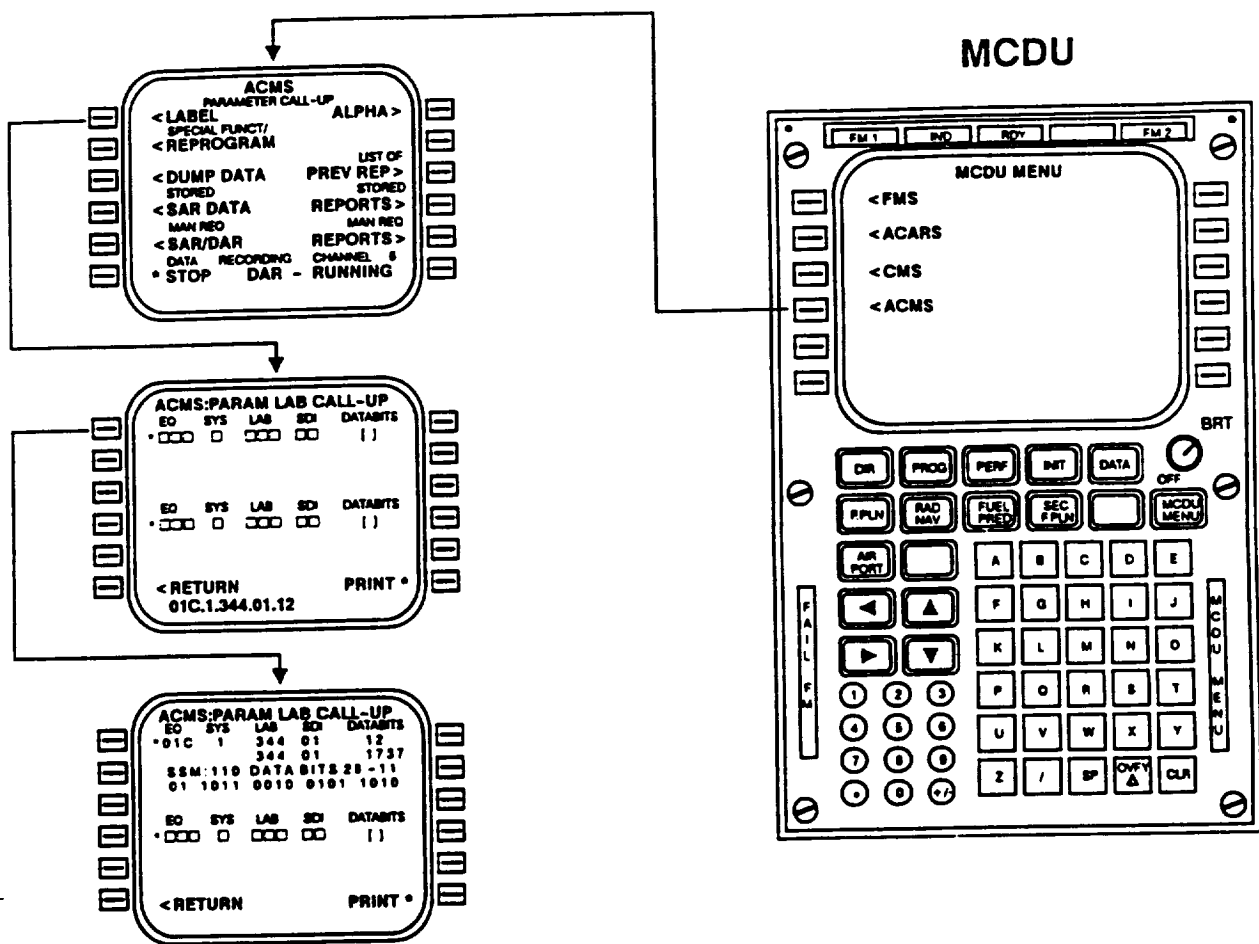


Figure A.1-3. ACMS Operation

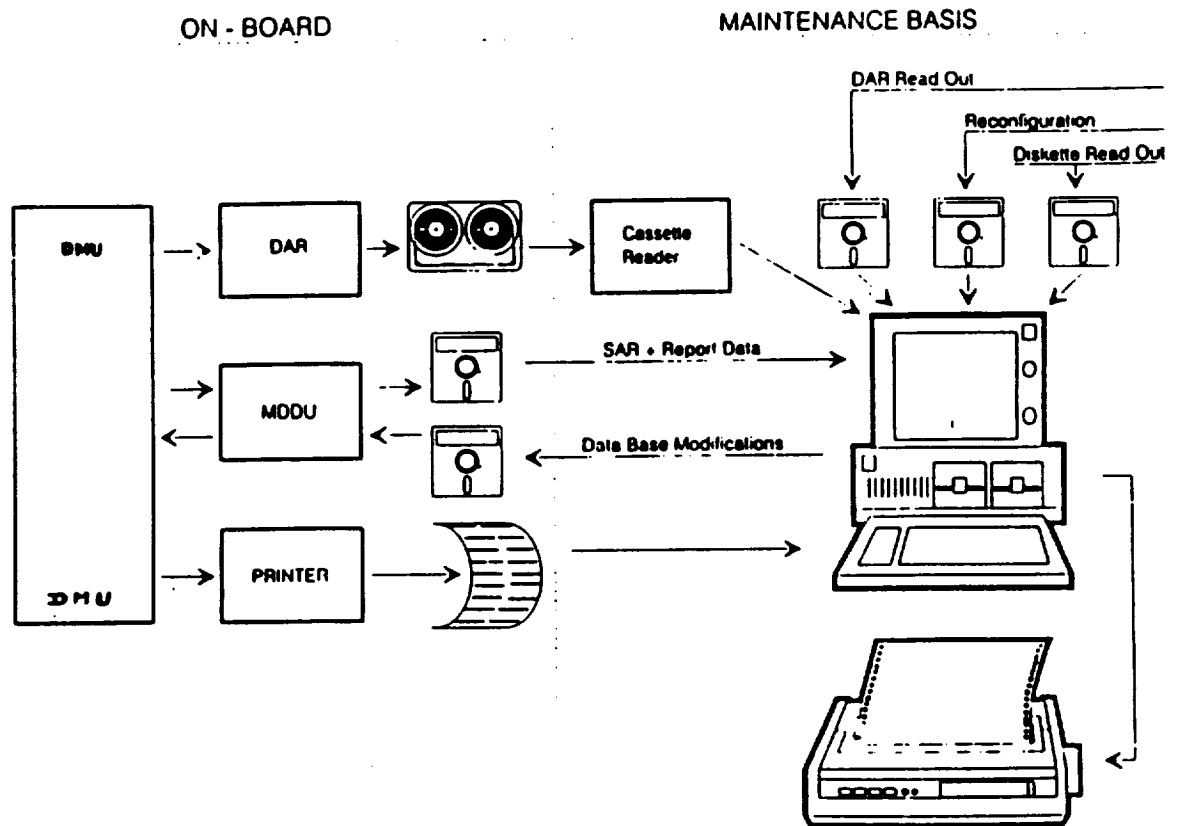


Figure A.1-4. ACMS Ground Interface Schematic

port, and flight number. The last item on line CC is a checksum (91). The fifth line, labeled C1, provides information indicating cruise flight (06); report, sequence number, type and code; and bleed status information. Line seven, labeled CE, gives total air temperature (-26°C), altitude (38,986 feet), calibrated airspeed (248 knots), Mach number (.800), gross weight (43.67 tons), center of gravity location (19.8%), and data management unit (DMU) version. The lines labeled EC, N1, S1, and D1 are for engine number one. The lines labeled EE, N2, S2, and T2 are for the other engine on the A320 aircraft. The information is shown and indicated as engine serial number (ESN), flight hours (EHRS), fuel flow (FF), and so on with N1, N2, EGT, etc.

The state of the art of the Deutsche Airbus DFDRS and ACMS concepts appear to be equivalent to projected levels of advancement for these types of equipment in the United States. Several European airlines are recording flight data similar to that obtained by the DFDRS in order to assess aircrew performance and to improve safety and training. It is generally agreed that the time has come for U.S. airlines to participate in such programs. The FAA has stated that it would only be interested in using aircrew performance data to improve training programs and safety and not for punitive purposes.

6.0 Non-Avionics Areas of Endeavor

Deutsche Airbus' non-avionics areas of endeavor include:

Materials Technology. Deutsche Airbus has taken a leading role in the development and manu-

facture of large structures able to withstand high static, dynamic, and thermal loads. Additional future technology areas include: carbon fiber reinforced plastics (CFRP) spoiler tests, CFRP aluminum-lithium wing structures, CFRP fuselage, and thermally loaded structures.

Aerodynamics. The company's emphasis is on the variable camber transonic laminar wing, which is considered an integral part of the total aircraft control loop, turbulence management, and research leading toward the hypersonic transport. Additional future technology areas include variable camber, aeroelastic modelling, hybrid laminarity, and supersonic and hypersonic transport studies.

Engines and Engine Integration. The company's emphasis is on ultra-high by-pass engines, turbo-ramjet engines for supersonic applications, and project components for the Sanger Space Transport System. Additional efforts include the superfan, propfan noise and interference effects, supersonic engines and intakes, and propfan integration.

Methods and Processes. Deutsche Airbus is preparing ambitious technological projects for which preliminary studies and work has been initiated. Emphasized are the integration of new systems and technologies into the MPC 75 regional airliner and feasibility studies for a successor to the Concord SST. Additional areas of interest include hypersonic transport support, complex simulations, and highly integrated development processes.

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      A320 ENGINE CRUISE REPORT <01>
      A/C ID DATE  UTC    FROM TO   FLT
CC  █████ JUN20 093534 LFBO EDHI 0002 91
      PH CNT    CODE BLEED STATUS
C1 06 01502 6001 42 0010 0 0100 39 > 98
      TAT  ALT    CAS MN  GW   CG  DMU/SW
CE N260 38986 240 000 4367 190 8080G0 07
      ESN    EHRS  ERT   ECYC  AP
EC 731204 00000 <<<<< 00001 12 F1
EE 731205 00000 <<<<< 00001 12 F4
      N1    NIC  N2    EGT  FF   PS13
N1 0071 0071 0906 5914 1005 05601 63
N2 0071 0071 0904 5096 1012 05626 70
      P25    T25  P3    T3    T5    VSV VBV
S1 10646 0504 1050 4125 3912 007 130 E2
S2 10500 0574 1055 4120 3944 007 107 00
      HPT LPT RAC GLE  PD TN  PT2  OIQH
T1 012 074 024 0027 39 096 04371 0000 FC
T2 012 074 025 0016 37 103 04410 0000 F1
      OIP OIT VB1 VB2 PHA EVH   ECW1
VC 040 006 010 002 202 00000 00001 68
VN 041 006 004 003 207 00000 00001 00

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Figure A.1-5. Typical Readout for Aircraft Engine Cruise Report Number 01

APPENDIX A2

SITE REPORTS

*Deutsche Forschungs-und Versuchsanstalt fur Luft-und Raumfahrt
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1.0 Date of Visit:

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Charles Homolka
Alan Angleman

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Volkmar Adam	Head of Flight Control Systems
Gunter Mansfeld	Flight Control Systems
Uwe Volckers	Head of Knowledge-Based Planning Systems
Ralf Beyer	Head of Human Engineering and Simulation
Dr. Norbert Furstenau	Measuring Techniques and Sensors

4.0 Facility Overview and Organization

The primary task of Deutsche Forschungsanstalt für Luft und Raumfahrt (DLR) is to establish a scientific-technical basis for the development and utilization of future aircraft and spacecraft. In the past few years, the application of energy technology has been established as a further key activity of DLR.

DLR's scientific-technical expertise lies with the institutes of its five scientific Research Departments: Flight Mechanics/Guidance and Control; Fluid Mechanics; Materials and Structures; Energetics; and Communication Technology and Remote Sensing (Figure A.2-1). Its expertise is also used in the construction and operation of large-scale test and simulation facilities, as well as space support installations. A great deal of importance is also attached to the management of scientific-technical projects.

The medium- and long-term perspectives for the programs are developed in the sectors of Aeronautics, Astronautics, and Energy Technology. DLR's research work, investment policy, and user-related services are in accordance with these programs.

The direction of the research and development work takes into account the aims of the Federal Government's relevant research programs, the medium- and long-range demand analysis of industry, and the possibilities for cooperation with universities performing fundamental research.

Coordinating with industrial partners, DLR focuses on preliminary research and development tasks prior to industrial application. These tasks are planned on a long-term basis, require continuous processing in a multi-disciplinary network and

cannot be undertaken by industry alone because of the financial risks involved.

Research activities undertaken by DLR are closely related to government-sponsored research programs. In performing its tasks, the research departments cooperate with other domestic and foreign research organizations, industry, universities, and federal and state administrations.

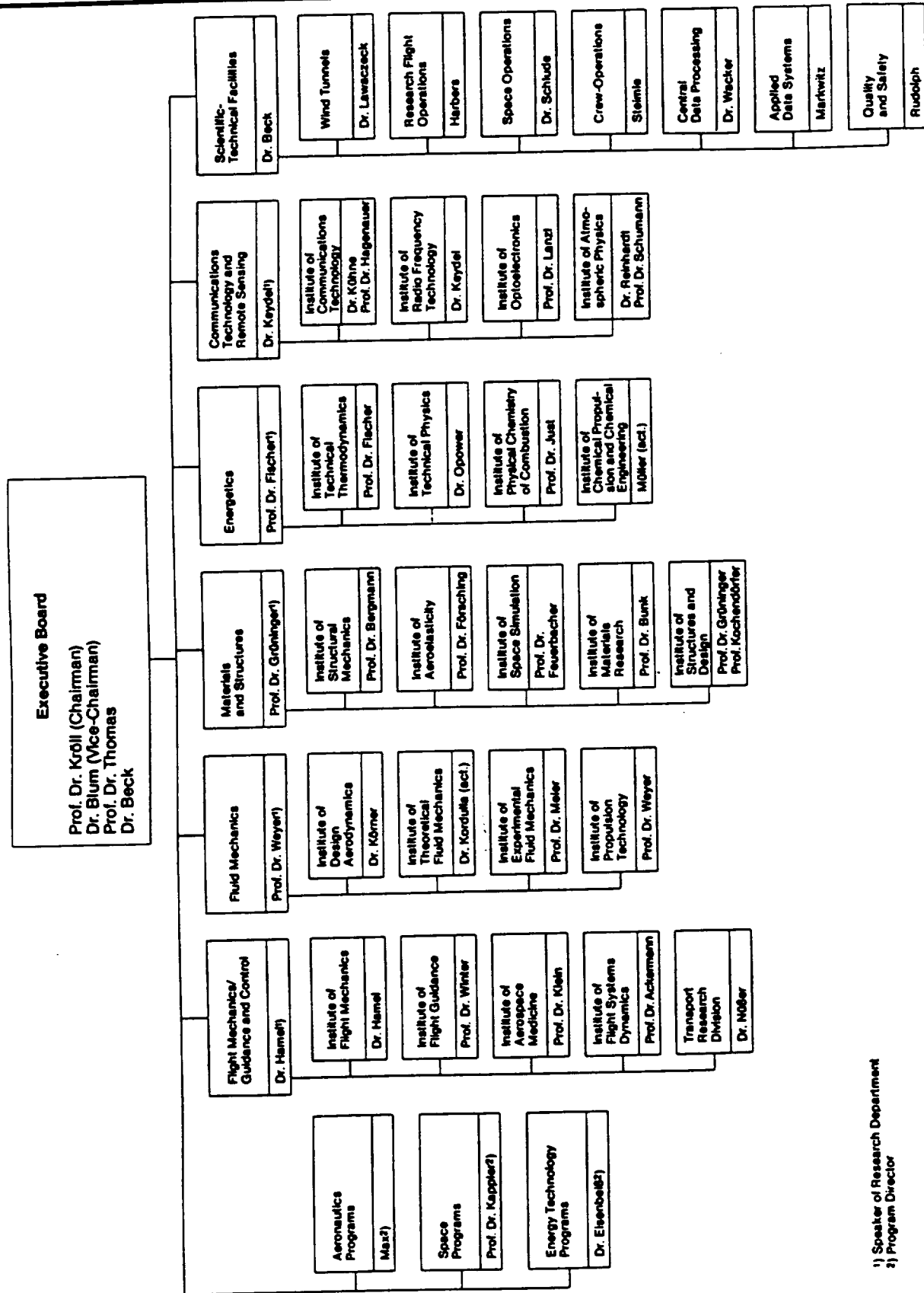
The research departments have a large selection of test facilities and equipment for use in their research programs. Large test facilities, such as wind tunnels, research aircraft, and large-scale computers are available at the Scientific-Technical Facilities Department and the Wind Tunnel Division. When necessary, non-DLR test equipment is also used. Examples of non-DLR test equipment include armed forces aircraft of Deutsche Lufthansa flight simulators.

The institutes, and thus the DLR, are located at five research centers:

- Köln-Porz (headquarters)
- Braunschweig
- Göttingen
- Stuttgart
- Oberpfaffenhofen

DLR employs 4,500 people. For 1990, the budget was 704 million DM, approximately \$400 million. The Federal Ministry of Research and Technology supplied 424 million DM, with 280 million DM coming from industry and government contracts.

The breakdown of employees at DLR (as of 1 January 1985) is shown in Table 2-1. The organization of the Research Department of Flight Mechanics/Guidance and Control is shown in



1) Speaker of Research Department
2) Program Director

Figure A.2-1. Organizational Structure of the DLR

Table A.2-1. Employee Distribution by Department

	Staff	%
Flight Mechanics/Guidance and Control (FF)	414	17
Fluid Mechanics	265	11
Materials and Structure	293	12
Energetics (EN)	297	12
Telecommunications Technology and Remote Sensing (NE)	287	12
Scientific-Technical Facilities Department (WT)	437	18
Wind Tunnels Division (HA-WK)	97	4
Project Management Department (PT)	317	100
TOTALS	2,407	100

Figure A.2-2. The labor distribution for this department is shown in Table A.2-2.

The Research Department of Flight Mechanics/Guidance and Control is divided into four institutes and one division, one in Oberpfaffenhofen, two in Köln-Porz, and two in Braunschweig (Figure A.2-2). The office for the Research Department of Flight Mechanics/Guidance and Control is currently located at the main facility in Braunschweig.

The activities of the Research Department of Flight Mechanics/Guidance and Control focus on the areas of behavior, guidance, control, optimization, and simulation of aeronautical, space, and other systems related to operational procedures characterized by large dynamic changes. The overall objectives are to assess and improve the performance and characteristics of complex systems and operational procedures and to provide methods and

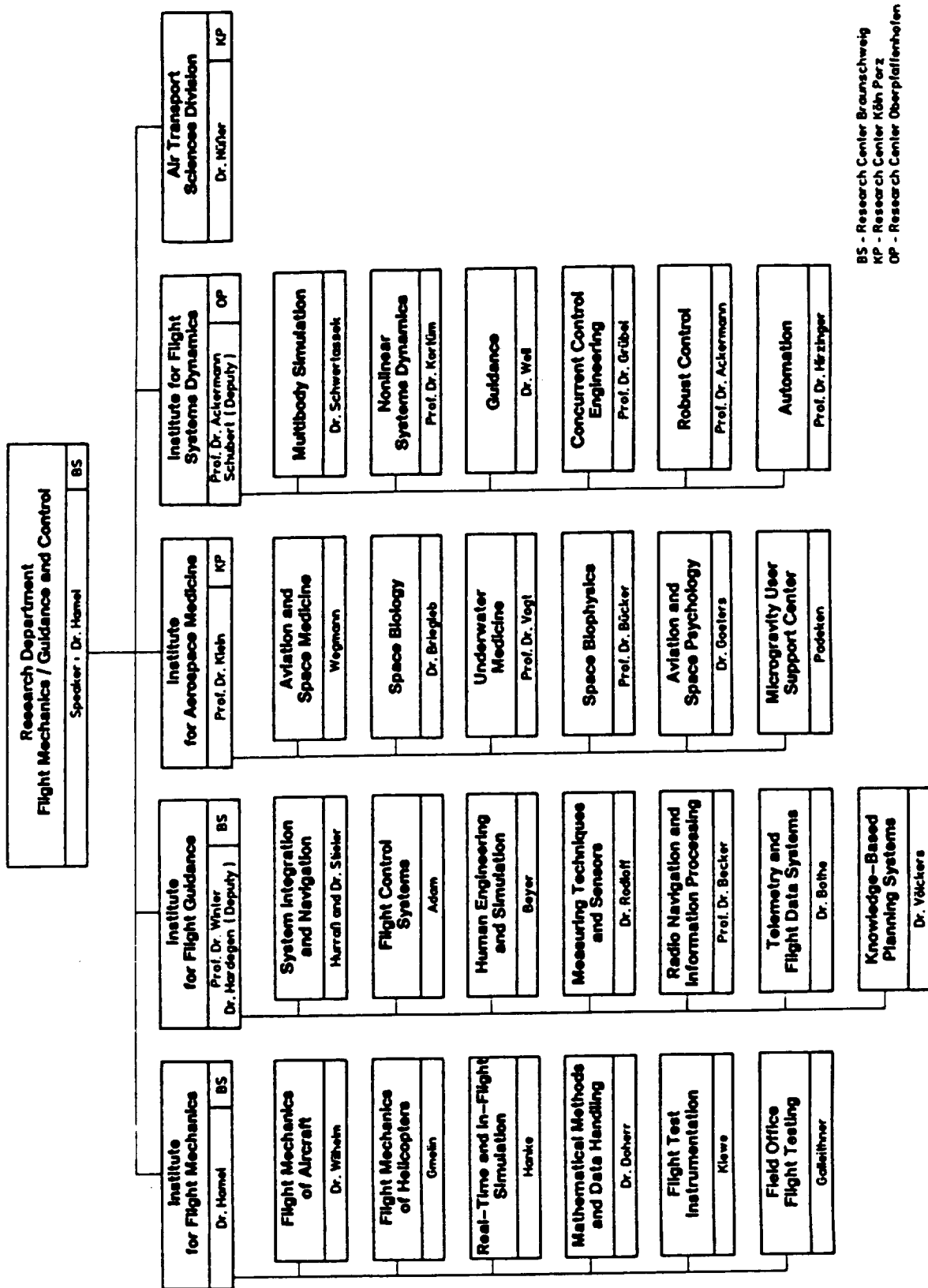
techniques for guidance and control procedures that incorporate the human decision-making processes.

The Aeronautical Research sector concentrates on improvement in airport operations, air traffic control, flight operations, human engineering, and flight characteristics/performance. The Space Research sector concentrates on operational tasks in connection with Spacelab flights and the application of zero gravity and other factors of the space milieu to life science research on humans, biological organisms, and molecules. The principal disciplines of the Technology Transfer sector are robotics, vehicle dynamics, and underwater technology.

The Research Department of Flight Mechanics/Guidance and Control appears to be involved in activities with strong similarities to NASA and FAA activities.

The institute for Flight Systems Dynamics in Oberpfaffenhofen is committed to the study of guidance, control, and dynamics of complex systems. Current work areas are multibody dynamics, guidance, control, automation, and guided missiles. Leading these areas is the development and operation of new control principles and guidance laws. Mathematical modelling and simulation are used to achieve these ends.

The Institute for Aerospace Medicine, located in Köln-Porz, investigates the effect of extreme environmental conditions on human behavior in performing technical operations. The goal of the Institute is to modify training methods to new systems, develop optimized situations and work environments, specify workload criteria, and produce a database on human behavior. The behavior of plants, animals, and molecules subjected to the space environment is also examined here.



BS - Research Center Braunschweig
 KP - Research Center Köln Parz
 OP - Research Center Oberpfaffenhofen

Figure A.2-2. Organizational Structure of the Research Department of Flight Mechanics/Guidance and Control

Table A.2-2. Employee Distribution for Research
Department of Flight Mechanics/
Guidance and Control

	Staff	%
Institute for Flight Mechanics	123	30
Institute for Flight Guidance	133	32
Institute for Aerospace Medicine	82	20
Institute for Flight Systems Dynamics	70	17
RD-Staff	6	1
TOTALS	414	100

Braunschweig is the home of the Institute for Flight Mechanics and the Institute for Flight Guidance.

The Institute for Flight Mechanics studies the dynamic behavior of actively controlled flight vehicles. The subject of active control and its coordination with pilot controls is of particular interest here. Flight characteristics and performance of aircraft using active control are examined for the purpose of improving designated operational needs such as low-altitude flight and for system errors and failures.

The Institute for Flight Guidance (IFG) is involved in the development of guidance systems for aircraft and air traffic control. The goals of the IFG are to define the limits of automation, designate the optimum level of task sharing between automated systems and man, and, where applicable, transfer human tasks to automated systems.

The Air Transport Science Division is concerned with system studies in the field of transport research, especially future developments in air traffic.

5.0 Avionics R&D Programs

The Institute for Flight Guidance is responsible for the development of advanced guidance and control systems for aircraft and air traffic control. The major avionics programs under investigation involve:

- Pilot-controller interactions
- Ergonomic design of display and control systems
- Study of the limits of automation
- Automatic control systems, including fault-tolerant control systems, automatic flight path control and computer-assisted air traffic control
- Improved sensors for navigation systems for enroute flight, approach and landing
- Use of gyroscopes and inertial sensors
- Use of microwave and laser tools for navigation systems

Navigation and air traffic control work includes the study of image data transmission for guidance and reconnaissance, air traffic flow near airports, strain on personnel, and an attempt to predict future air traffic scenarios. The INS is working to improve the gyro and eliminate the lock-in problem that prevents the gyroscope from supplying a usable output below a certain rate of turn.

Work in fiber-optic sensors and optical components is under way in a number of areas. Interferometric strain gauges that use optical fibers will be installed on test bed aircraft to evaluate the

concept of "smart skin" aircraft, aircraft in which the strain in structures can be measured. Research is also being conducted on the generation of electrical power for sensors using optical-to-electrical conversion. In addition, research on bi-stable and multi-stable interferometers to be used as optical switches for digital sensors and actuators is being conducted. A fly-by-light demonstration using fiber-optic links and optical-to-electrical power conversion on a helicopter trim actuator for the tail rotor was demonstrated.

The use of optical-fiber-laced composite structures is being studied, starting with preliminary flight tests of a simple optical fiber pasted to the test bed aircraft wing to determine if the technique can provide a useful learning tool. Investigations are also being conducted with optical switches to simplify electro-optic architectures.

In the human engineering and simulation area, work focuses on people and their working environment. The goal is to investigate and develop new designs that increase safety and economy without sacrificing performance or removing the human element from the control loop.

Analyses of the stress involved in the act of flying an aircraft are based on psychophysiological parameters derived from variables including circulatory system data and biochemical analyses of hormone excretion rates (i.e., adrenaline/nor-adrenaline). The performance workload/stress acceptance criteria obtained are checked for statistical and operational significance. However, since no standards exist to evaluate the data against, evaluations are based on the assumed equivalence of input variables and system performance workload/stress acceptance, as well as the null hypothesis of "no change" in relation to the existing conditions.

The goal of ATC is an exchange of information regarding weather and aircraft data between the cockpit and traffic control tower that will result in better overall performance and safety. To address the growing interaction between flight guidance and flight control systems, component research continues. Through better design of aircraft panels and ATC hardware, pilot and controller performance, stress, and cost factors should improve.

Comprehensive flight tests have shown that low-altitude guidance of helicopters at night using terrestrial navigation for transport operations and search and rescue operations can be improved by using a combination of electro-optical sensors as visual aids, electronic displays for instrumentation, and Doppler navigation.

IFG is improving pilot access to information on aircraft position, engine status, and aircraft performance. Touch-pad controls, mouse controls, and voice commands are all methods for the pilot to access information from the computer. Voice commands from the pilot are especially problematic since different languages must be dealt with.

A simulation concept has been implemented to research the overall air traffic system with particular attention to the needs of the humans in the loop. The ground part of this system, the Air Traffic Management and Operation Simulator (ATMOS), has two controller workstations, six terminals, and a total of 36 simulated aircraft. The aircraft simulated include the HFB-320, the Airbus A300, and the test bed Advanced Technologies Testing Aircraft System (ATTAS). These simulations are flown by professional pilots guided by ATC. The ATC simulator provides experimental support to the COMPAS project.

IFG is especially concerned about traffic flow control during approach and landing. Final separation of aircraft can only be achieved with the aid of the guidance system. Algorithms have been developed to calculate the 4-D flight path to be assigned to the aircraft by the ATC. This permits consideration of the existing wind along the flight path and determination of wind speed and direction. The COMPAS is designed to improve landing and take-off patterns by using the flight plan and radar data from incoming flights to provide a look-ahead capability for the controller.

Fault-tolerant software and hardware designs are being studied as part of the control reliability improvements upon which DLR is working, particularly for helicopters.

The Institute currently uses a VFW 614 twin-jet and Dornier DO 228 twin-turboprop for fixed-wing test purposes. The VFW 614 (ATTAS) is equipped with a remote experimental cockpit similar to the NASA Langley Research Center B-737.

APPENDIX A3

SITE REPORT

Aerospatiale Division Avions
316, route de Bayonne
31060 Toulouse, France
Telephone: (1) 42 24
Telefax: AISPA 620 059 F

1.0 Date of Visit:

18 June 1991

2.0 Panel Members:

Daniel Martinec
Robert Baumbick
Monica Mayton
Ellis Hitt
Joseph Traybar
Cornelius Leondes
Joseph Schwind
Cary Spitzer
Ramon De Paula
Charles Homolka
Alan Angleman

3.0 Principal Contacts at Facility:

Dominic Berger	Head, Aircraft Division Office (AS/A/DET)
Hughes Subra De Salafa	Systems Research and Workshop Department (AS/A/DET/SQIP)
Marie-Claude Pomery	Systems Research and Workshop Department (AS/A/DET/SY/SQIP)
Christian Favre	Flight Controls Department (AS/A/DET/SY/MCDV)
Jean-Paul Domergue	Systems Research and Workshop Department (AS/A/DET/SY/SQIP)
Jean Grossin	Avionics Department (AS/A/DET/SY/AVIC)

4.0 Facility Overview

Aerospatiale is a cooperative venture and owns shares of many important European aerospace organizations, as follows:

- Airbus Industries (37.9%)
- Avionday Transport Regional (50%)
- Eurocopter (50%)
- Arianespace (8.2%)
- Eurosatellite (24%)
- Euromissile (50%)
- EMDG (33%)

Aerospatiale is divided between the Space and Strategic Systems Group and the Aircraft Group. Main products of the Space and Strategic Systems Group include:

- Ariane launch vehicle
- Hermes spaceplane
- Satellites
 - METEOS
 - ARABSAT
 - TDF-TV-SAT
 - EUTELSAT II
- Intermediate range ballistic missile (SSBS)
- Submarine launch ballistic missile (MSBS)
- HADES

The main products of the aircraft group are the Airbus family (A300, A300/600, A310, A320, A321, A330, A340), the Avion de Transport Regional (ATR) 42 and ATR 72, and the Concorde. Military products produced by the Aircraft group consist of the TRANSALL C160 and EPSILON (Socata), the Avion de Transport Supersonique Futur, and the Avion à Grande Vitessa, which is

being, designed to operate in the mach 4 to mach 5 range.

In 1989, Aerospatiale had sales of 12 billion francs. The breakdown of earned income shows Airbus (68%) is the most active division, with ATR (15%) and various departments (17%) rounding out the total. Exported products accounted for 74% of Aerospatiale's total sales. Although Aerospatiale is a government-owned institution, it is akin to a private company and earns a profit. Aerospatiale is required to pay the government a specified amount earned for each aircraft as repayment for a loan taken in order to establish the company.

Significant milestones in the history of Aerospatiale's Avions Division include the first flights of the CARAVELLE (1955), the first-generation TRANSALL (1967), and Concord 001 (1969). Aerospatiale has also participated in the first flights of the Airbus A300 (1972), as well as the entire Airbus family; the EPSILON (1979); and the ATR 42 and ATR 72.

Aerospatiale participates in two European joint ventures, the Groupement d'Interet Economique (G.I.E.) Airbus Industries and the G.I.E. ATR. G.I.E. Airbus Industries, created in 1970, has four members who act as shareholders as well as manufacturers. The breakdown is as follows:

- Aerospatiale - 37.9%
- Deutsche Aerospace - 37.9%
- British Aerospace - 20%
- Construcciones Aeronauticas S.A. (CASA) Spain - 4.2%

Associate members of G.I.E. Airbus Industries include Fokker N.V. (the Netherlands) and Belairbus (Belgium). G.I.E. ATR, created in 1982, consists of two companies, Aerospatiale (50%) and Aeritalia (50%).

5.0 Avionics R&D Programs

Aerospatiale is continuing with the development of the Airbus family of aircraft. The A340 was slated to make its first flight in October 1991 and enter service in the autumn of 1992, followed closely by the entry of the A330 into service in the autumn of 1993. The complexity and volume of on-board software and the number of data links is rapidly increasing. On-board computing capacity is also increasing. The A340 uses automatic software development tools, resulting in very few software faults. The necessary debugging actions per 100,000 kB of software was 10 or less. The flight control systems on the A340 use analog sensors that provide analog inputs to the flight control computers. The pilot input is via an ARINC 429 data bus. The output to the hydraulic actuators is analog. Aerospatiale uses dissimilar redundancy with different hardware and different software from two different manufacturers in a dual-dual configuration. A mechanical backup is installed on two control axes. The hydraulics are powered by three different sources.

5.1 Software Development

Aerospatiale is creating various aircraft systems development methods and tools. The Specification Assistee par Ordinateur (SAO) (computer-aided specification) program provides a standardized graphic language for representation of logic and control laws with consistency in control and modification procedures and related configuration management. It uses a graphics language and graphics editor. SAO includes a signal data bank, an aircraft data bank, and a VAPS, a rapid prototyping tool for use on silicon graphics workstations that was developed by a Canadian firm. A number of U.S. manufacturers, as well as the U.S. Air Force, use the VAPS tool.

Aerospatiale also uses other devices to perform automatic coding and specification. This coding, which is executed in the simulator, contains some real-time and some single- or multi-channel code, as well as batch code. The simulated results are compared to a model of the plane.

5.2 Advanced Cockpit and Operational Systems

In the area of advanced cockpit and operational systems, the main research and development programs contributing to cockpit design are:

- EPOPEE III (Etude Prospective d'Organisation d'un Poste d'Equipage Ergonomique - Investigation of the ergonomics of the piloting station)
- PREFACE (Programme de Recherche sur l'Environnement futur des Avions Civils et leurs Equipements - Research programme on the impact on civil aircraft and equipment of future environment evolution)
- FANSTIC (Future ATC, New System and Technology Impact on Cockpit)

Partners in the EPOPEE III program include Aerospatiale Avionics and System Directorate, Sfena, Thompson-CSF, and Crouzet. The EPOPEE III program performs studies on 3-D visualization, TCAS II alert displays, flat panel implementation, voice control, and touch control panels. The goal of the program is to retrofit simulators with an advanced organization of the controls and displays and develop new cockpit layouts.

PREFACE and FANSTIC are joint programs. Phase I of PREFACE/FANSTIC consists

of studies of human operator capability and weakness assessments. Results are to be used to develop an incident/accident database and formulate theoretical studies on pilot behavior. The impact on flight deck and operational systems as they pertain to the evolution of the air transport environment are of particular interest. Also, PREFACE/FANSTIC Phase I will develop new symbologies in relationship to the improved operational system requirements. Phase I is examining the concept of the paper-free cockpit through the use of fully integrated electronic libraries in the cockpit. Evaluation of the new technologies of full implementation of LCDs and optical mass memory will be performed. Phase I will conclude with the design and implementation of improved displays and controls resulting from the studies.

Phase II of PREFACE/FANSTIC intends to continue with the human factors work begun in Phase I. Research will expand with an evaluation of the impact of new technology on the man-machine interface, the development of improved ground-to-air communication networks, and the development of new systems such as:

- Taxi guidance
- Takeoff monitoring systems
- Windshear prediction systems

Aerospatiale intends to maintain its leadership in cockpit design. The cockpits of tomorrow will be designed according to Aerospatiale's main philosophy:

- Necessary use of state-of-the-art, but well-proven, technology
- Aircrew involvement in mission completion and top-level decision-making in the cockpit

However, Aerospatiale is not planning any further significant steps in cockpit automation.

5.3 Flight Controls

Aerospatiale intends to pursue flight control systems and avionics integration in order to achieve weight reduction, savings in recurring cost, and reliability gains. Aerospatiale has experience with electrically powered actuators which result in weight reduction and savings in recurring costs. They have experimented with electrical actuation of some flight control surfaces. The standard practice with flutter compression is to use two servo control systems per aircraft.

Aerospatiale expects to achieve a decreased LRU count and still obtain optimization of the flight control system/avionics architecture. The next-generation architecture could use modular units to reduce volume. However, with such a system, an increase in cost is expected. Improved flight control systems must be able to operate for 18 hours without any auxiliary cooling.

Aerospatiale intends to pursue the integration of new functions with the flight control system, including flutter control, with an active control system under consideration. The flutter bandwidth with which they are concerned extends to 215 Hz. Their current investigation into electrically powered actuators require rates as high as 200 deg/sec for functions such as load alleviation. These rates are difficult to achieve with electromechanical actuators. Aerospatiale also has under development a single integrated electrohydraulic assembly (EHA), which is not distributed. This assembly contains the pump accumulator and actuator in a single unit. Current problems include seal leakage.

Aerospatiale believes that the electrohydraulic static actuator has potential application to

the next generation of aircraft, while the electro-mechanical actuator requires further investigation. They are investigating mechanical linkage suppression by applying optical data transmission while still using dissimilar technology.

Aerospatiale also believes the avionics boom will continue to increase in volume due to the higher number of functions. Advances in mechanical linkage suppression require new technology sensors that will interface with optical data buses.

5.4 Optical Systems

Aerospatiale is involved with optical applications in fly-by-light systems. Currently, there are two programs for research in this area:

- CLOVIS - currently flying on an Air-Inter A300 with over 10,000 hrs.
- CLOVIS II - involves an optical position sensor, located on the low speed aileron, that uses intensity-modulation to sense position.

Aerospatiale is applying optical technology in an electronic library system. Optical cables with teflon jackets and a 1.5-mm outer diameter are installed using standard ties. Aerospatiale has not yet encountered a problem in integrating optical bundles with electrical bundles.

In a new project, Aerospatiale is investigating the use of an optical backplane to interface electronic units with interface units through networks to optical/electrical sensors as well as optical incident-position and temperature sensors. These inputs include the anemo-baro sensor as well as the aforementioned sensors.

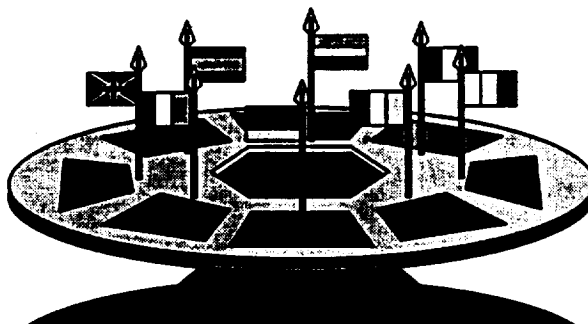
Aerospatiale is also developing new sensors for optical sensing, windshear sensing, ground collision avoidance, and possibly ice forecasting and storm detection. Aerospatiale's efforts include the establishment of requirements and architectures for sensors.

A condensed version of the Aerospatiale briefing to the NASA panel is provided on pages A3-6 to A3-25.



AEROSPATIALE and European cooperative venture organizations

(Aerospatiale share)



AIRBUS INDUSTRIE (S.I.E.)	37.9%	ARIANESPACE	8.2%
AVION DE TRANSPORT REGIONAL (S.I.E.)	50%	EUROSATELLITE	24%
EUROCOPTER (S.I.E.)	50%	EUROMISSILE (S.I.E.)	50%
		EMDG (S.I.E.)	33%

JAN 90



MAIN PRODUCTS SPACE AND STRATEGIC SYSTEMS



ARIANE LAUNCH VEHICLE
HERMES SPACEPLANE
SATELLITES

- METEOSAT
- ARABSAT
- TDF - TV-SAT
- EUTELSAT II



SSBS (IRBM)
MSBS (SLBM)
HADES

JAN 90



MAIN PRODUCTS AIRCRAFT



AIRBUS
A300, A300-600, A310
A320, A321
A330, A340

ATR
ATR42, ATR72

CONCORDE



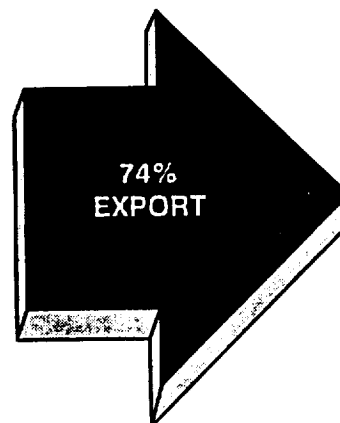
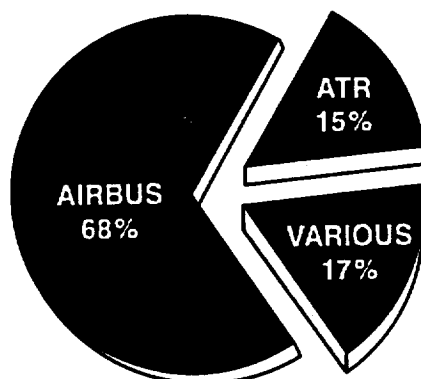
TRANSALL C160

EPSILON (SOCATA)

JAN 90



TURNOVER 1989 12 billion Francs



JAN 90



MILESTONES

MAY	1955	first flight CARAVELLE
APRIL	1967	first flight TRANSALL (first generation)
MARCH	1969	first flight CONCORDE 001
DECEMBER	1970	creation of GIE AIRBUS INDUSTRIE
OCTOBER	1972	first flight AIRBUS A300
DECEMBER	1979	first flight EPSILON
APRIL	1981	first flight TRANSALL (second Generation)
FEBRUARY	1982	creation of GIE ATR
APRIL	1982	first flight A310
JULY	1983	first flight AIRBUS A300-600
AUGUST	1984	first flight ATR 42
JULY	1985	first flight AIRBUS A310-300
FEBRUARY	1987	first flight AIRBUS A320
JUNE	1987	launching of AIRBUS A330 and A340
OCTOBER	1988	first flight ATR 72
JUNE	1989	delivery of 500ème AIRBUS
NOVEMBER	1989	launching of l'AIRBUS A321

JAN 90



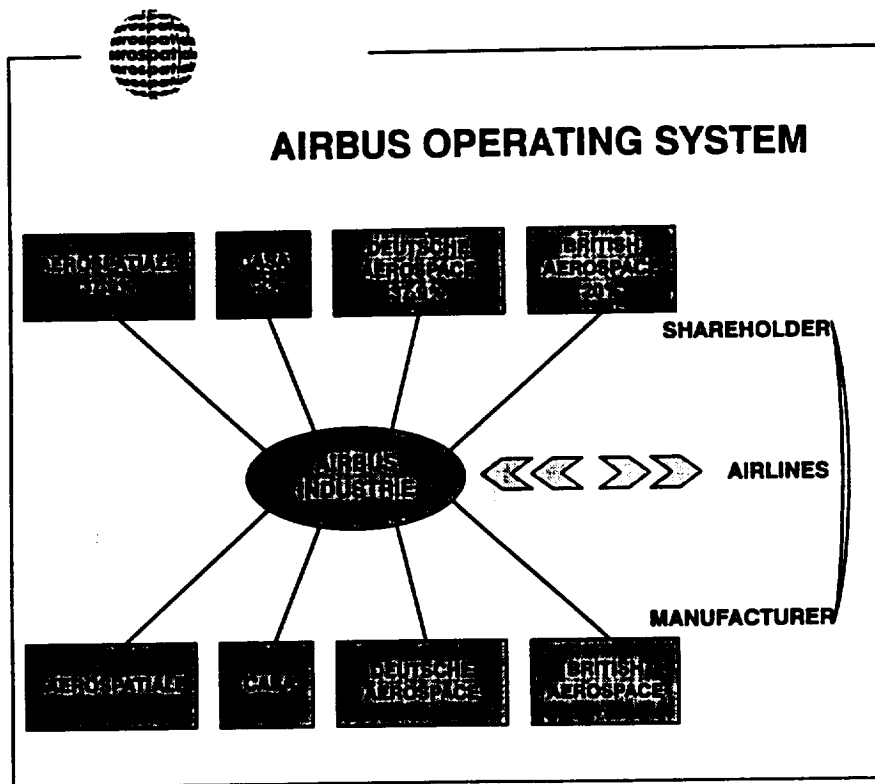
EUROPEAN JOINT VENTURES



Aerospace (France)	37.9%	Aerospatiale	50%
Deutsche Aerospace (FRG)	37.9%	Aeritalia	50%
British Aerospace (GPR)	20%		
Construcciones Aeronauticas S.A. Spain	4.2%		
Associated members Fokker N.V. (Netherlands) Belairbus (Belgium)			

G.I.E. : Groupement d'Intérêt Economique

JAN 90



JAN 90

AIRBUS PROGRAMS MILESTONES

MAY	1969	launching of A300
MAY	1974	entry-into-service A300 (Air France)
JULY	1978	launching of A310
DECEMBER	1980	launching of A310-600 (A300 stretched version)
APRIL	1983	entry-into-service of A310 (Lufthansa and Swissair)
MARCH	1984	launching of A320
APRIL	1984	entry-into-service of A300-600 (Saudia)
JUNE	1987	launching of A330 and A340
APRIL	1988	entry-into-service of A320 (Air France and British Airways)
JUNE	1989	entry-into-service of A321 (Northwest)
NOVEMBER	1989	Launching of A321
AUTUMN	1992	entry-into-service of A340
AUTUMN	1993	entry-into-service of A330
SPRING	1994	entry-into-service of A321

JAN 90



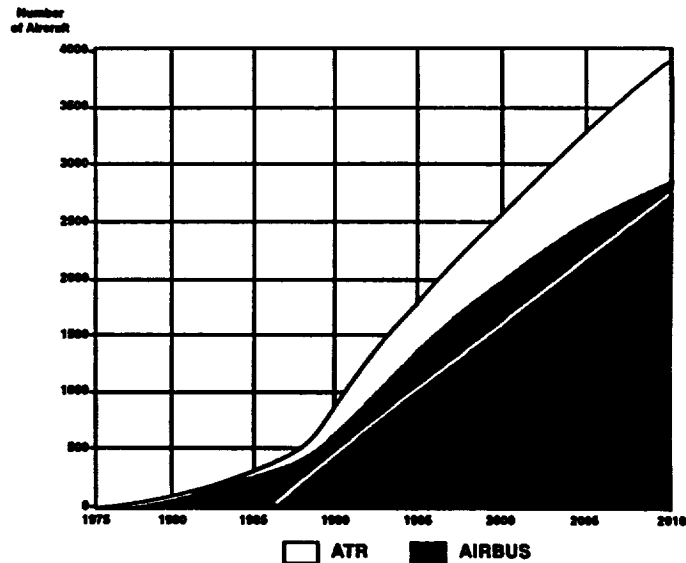
ATR PROGRAM MILESTONES

JULY	1980	Joint venture agreement between AEROSPATIALE/AERITALIA for commuter (Avion de Transport Régional)
NOVEMBER	1981	Launching of ATR 42 program
FEBRUARY	1982	Creation of G.I.E. Avions de Transport Régional: 50% AEROSPATIALE/50% AEROITALIA
AUGUST	1984	ATR 42 first flight
DECEMBER	1985	First delivery ATR 42 (Air Littoral)
JANUARY	1986	Launching of ATR 72 program
JULY	1986	First delivery of ATR 42 (Regional Air USA)
OCTOBER	1988	ATR 72 first flight
OCTOBER	1989	First delivery of ATR 72 to Kar Air (Finland)

JAN 90



AIRBUS AND ATR IN SERVICE



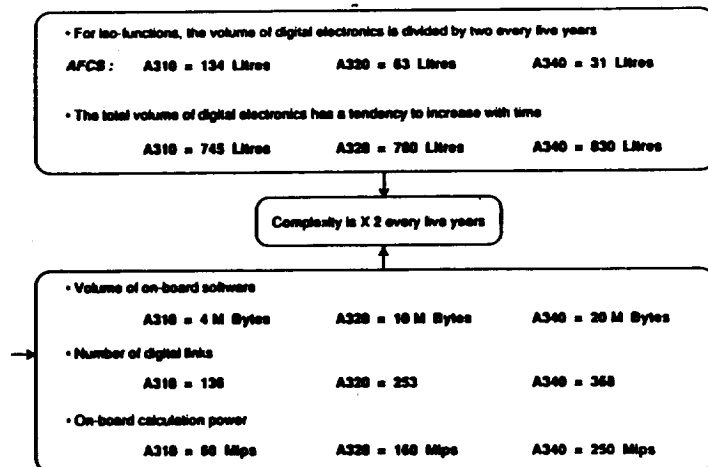
JAN 90

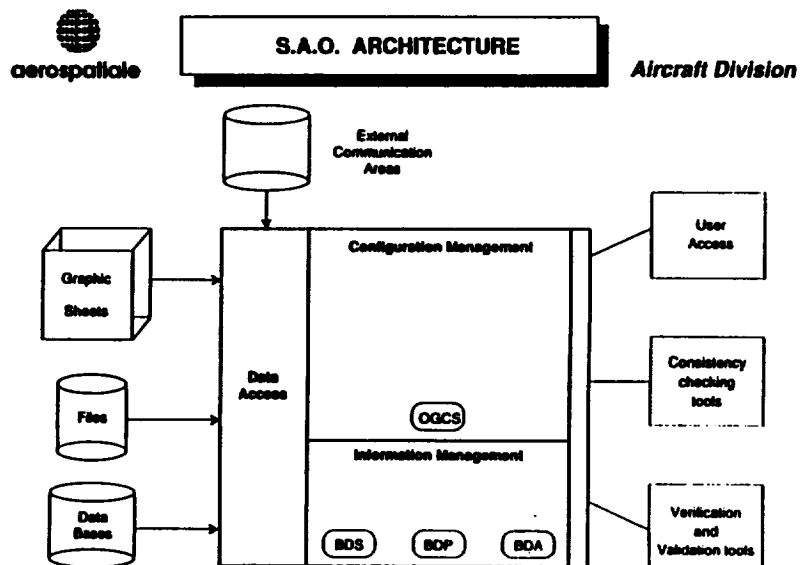
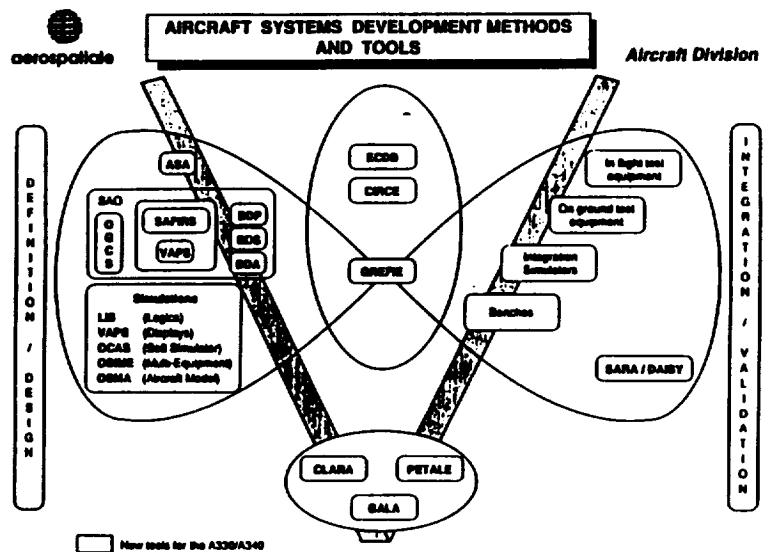
PRESENTATION TO AVIONICS EXPERTS OF NASA PANEL

JUNE 18, 1991

EVOLUTION OF DIGITAL SYSTEMS

Aircraft Division





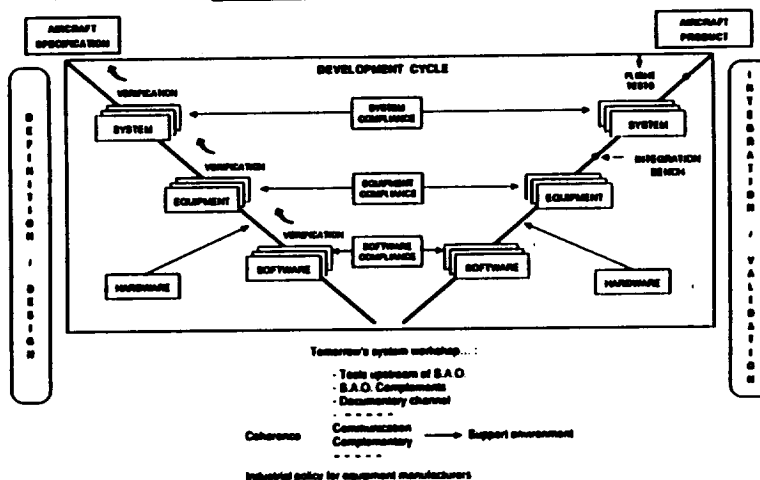
FIGURES

Aircraft Division

AIRCRAFT	A310	A320	A340
Number of different + redundant items of digital equipment	$53 + 24 = 77$	$56 + 46 = 102$	$67 + 48 = 115$
Volume of on-board software in mbytes	4	10	15 TO 20
Equipment under AS responsibility	$47 + 23 = 70$	$38 + 37 = 75$	$48 + 38 = 87$
Volume in mbytes	3.8	9	13 TO 18
Necessary debugging actions per 100 Kbytes software	Several hundred	several dozen	zero to less than 10

SYSTEM WORKSHOP

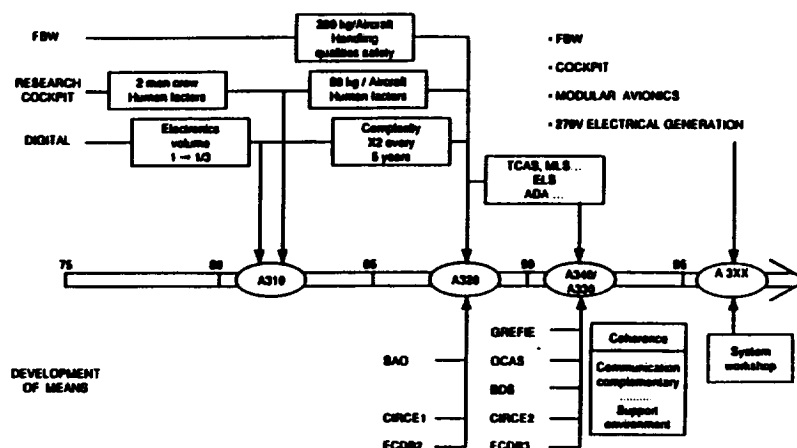
Aircraft Division





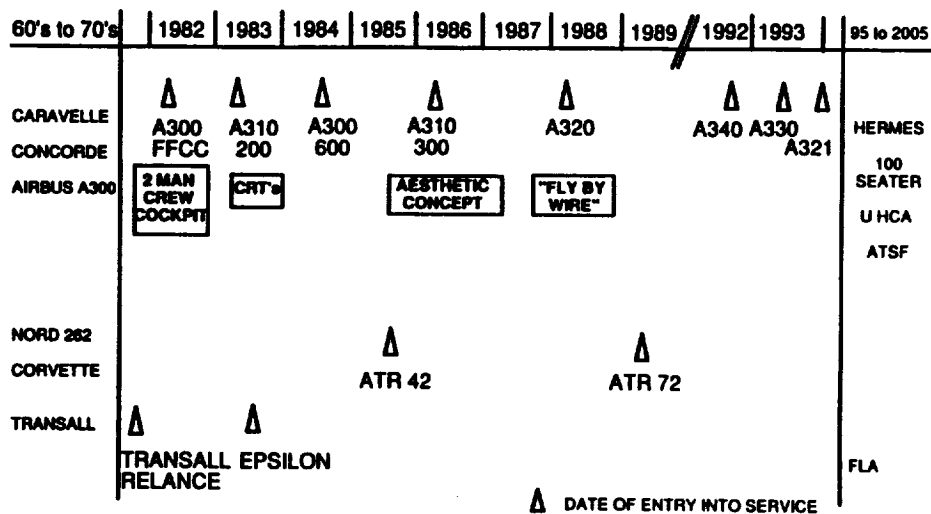
RESEARCH AND SYSTEMS

Aircraft Division



aerospatiale

AEROSPATIALE EXPERIENCE IN COCKPIT DESIGN

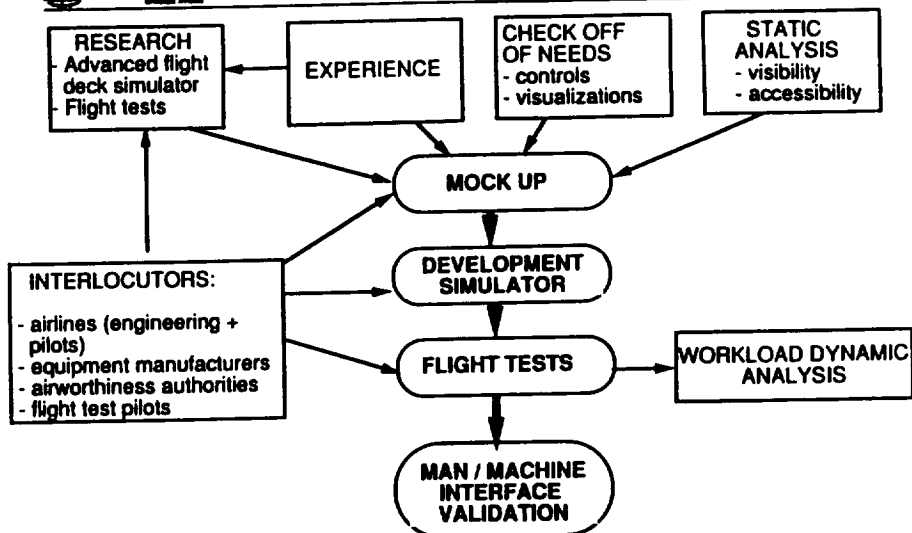


PRESENTATION TO NASA - JUNE 18 th, 1991

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COCKPIT DEVELOPMENT METHODOLOGY



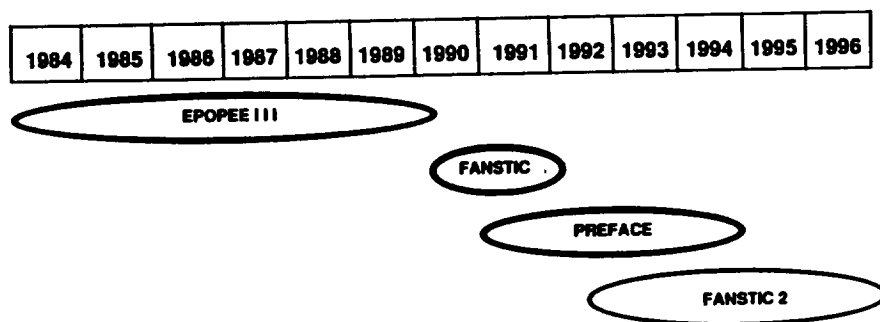
PRESENTATION TO NASA - JUNE 18 th, 1991

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COCKPIT RESEARCH FRAMEWORK

PROGRAMMES



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MAIN RESEARCH PROGRAMMES

EPOPEE III : Etude Prospective d'Organisation d'un Poste d'Equipe Ergonomique (Investigation of the ergonomics of the piloting station)

NATIONAL PROGRAMME

COORDINATOR : AEROSPATIALE TECHNICAL DIRECTORATE

PARTNERS : - AEROSPATIALE AVIONIC AND SYSTEM DIRECTORATE

- SFENA
- THOMSON - CSF
- CROUZET
- TEAM

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MAIN RESEARCH PROGRAMMES

PREFACE : Programme de Recherche sur l'Environnement Futur des Avions Civils et leurs Equipements (Research programme on impact on civil aircraft and equipment of future environment evolution)

NATIONAL PROGRAMME

COORDINATOR : AEROSPATIALE

PARTNERS : - SEXTANT AVIONIQUE
- DGAC (CENA)

FANSTIC : Future ATC, New System and Technology Impact on Cockpit

EUROPEAN COOPERATION

COORDINATOR : AEROSPATIALE

PARTNERS : 8 COUNTRIES, 14 MEMBERS (AIRCRAFT OR
EQUIPMENT MANUFACTURERS, RESEARCH CENTERS, UNIVERSITIES)

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MAIN RESEARCH AXES

EPOPEE III

- RETROFIT OF SIMULATOR WITH ADVANCED ORGANIZATION OF CONTROLS /
DISPLAYS AND NEW COCKPIT LAYOUT

- SHORT MOTION CONTROLS
- THROTTLE (SPEED RATE CONTROL)

- STUDIES ON :

- 3D VISUALIZATION
- T-CAS II ALERT DISPLAY
- FLAT PANEL IMPLEMENTATION (PFD / ND, STANDBY INSTRUMENT)
- VOICE CONTROL (DVI, DVO)
- TOUCH CONTROL PANEL
- G-CAS

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MAIN RESEARCH AXES

PREFACE / FANSTIC PHASE 1

- HUMAN OPERATOR CAPABILITY / WEAKNESS ASSESSMENT

- INCIDENT / ACCIDENT DATA BASE
- THEORITICAL STUDY ON PILOT BEHAVIOUR
- EXPERIMENTAL STUDY

- IMPACT ON FLIGHT DECK AND OPERATIONAL SYSTEMS OF AIR TRANSPORT
ENVIRONMENT EVOLUTION (SYSTEM EVOLUTION, MMI)

- MLS
- T-CAS III
- ACARS
- SAT-COM
- DATA LINK ATC

- NEW SYMBOLOGIES IN RELATIONSHIP WITH NEW OPERATIONAL SYSTEM
REQUIREMENTS

AOET/SY/SOP 451-031/01

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MAIN FUTURE RESEARCH AXES

PREFACE / FANSTIC PHASE 1 (CONT'D)

- STUDY ON AN ELECTRONIC LIBRARY SYSTEM FULLY INTEGRATED INTO THE AVIONICS AND THE COCKPIT ("PAPER FREE COCKPIT")
- NEW TECHNOLOGY EVALUATION :
 - * FULL IMPLEMENTATION OF LCD
 - * OPTICAL MASS MEMORY
- DESIGN AND IMPLEMENTATION INTO THE RESEARCH SIMULATOR OF IMPROVED DISPLAYS AND CONTROLS RESULTING FROM A.M. STUDIES AND NEW TECHNOLOGY AVAILABILITY

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MAIN FUTURE RESEARCH AXES

PREFACE / FANSTIC PHASE 2

- HUMAN FACTORS
- NEW TECHNOLOGY IMPACT ON MMI (VISUALIZATION, VOICE CONTROL, DESIGNATION SYSTEMS ...)
- GROUND / AIR COOPERATION AND COMMUNICATION NETWORK
- NEW SYSTEMS :
 - * TAXI GUIDANCE
 - * TAKE OFF MONITORING SYSTEM
 - * WINDSHEAR PREDICTION SYSTEM

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CONCLUSION

- AEROSPATIALE INTENDS TO GO ON KEEPING ITS LEADERSHIP IN COCKPIT DESIGN
 - THE TOMORROW COCKPITS AND OPERATIONAL SYSTEMS WILL BE DESIGNED ACCORDING TO MAIN PHILOSOPHY PRINCIPLES APPLIED BY AEROSPATIALE FOR A WHILE :
 - NECESSARY USE OF UP TO DATE BUT MATURE AND WELL PROVEN TECHNOLOGY
 - CREW DEEPLY INVOLVED IN MISSION COMPLETION AND MACHINE MANAGEMENT AT TOP DECISION LEVEL
- IN ADDITION :
- NO FURTHER SIGNIFICANT STEP IN AUTOMATION

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FUTURE FLIGHT CONTROL SYSTEMS

2/ Research axes and potential gains

2.1 Electrically powered actuators-->weight & R.C. gains

The study is performed in two complementary directions:

a/ Technology analysis, development and test:

EMA (Electro Mechanical Actuators)
and EHA (Electro Hydro static actuators).

b/ Survey of the possible FCS architectures based on the foreseeable technology

Optimization of the Flight Control System with its associated energy sources

Presentation to NASA June 18th 1991



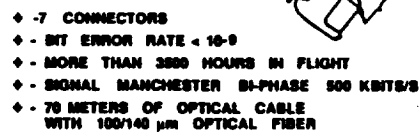
LABORATORY MOCK-UP OF AN EMERGENCY FLIGHT BY LIGHT CONTROL MODE



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CLOVIS EXPERIMENTATION IS : AEROSPATIALE AIR INTER
CABELTEL SOURIAU
SEXTANT AVIONIQUE



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OPTICAL TECHNOLOGY

NETWORK BASED ON A STAR LAYERED TOPOLOGY

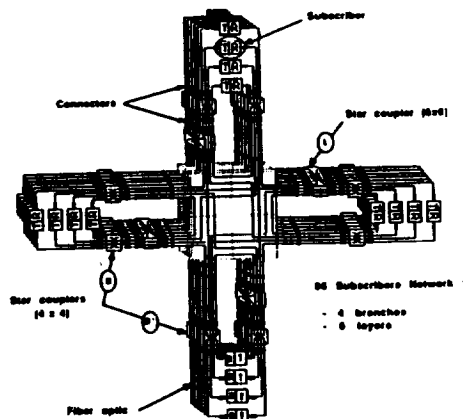
ARCHITECTURE FOR A TYPICAL 96 SUBSCRIBER APPLICATION

ADVANTAGES :

- HIGH POSSIBLE NUMBER OF SUBSCRIBERS
- USE OF :
CONVENTIONAL AND RELIABLE COMPONENTS
ALL TYPES OF FIBER (SMC/SMD, MCS, POF)
- PREFERENTIAL MODULAR STRUCTURE
- IMPORTANT GROWTH POTENTIAL
- ALLOWS INTERNAL SEGREGATED ROUTES
- HIGH GLOBAL RELIABILITY EXPECTED
- WELL ADAPTED TO AN AIRCRAFT SCHEME

DRAWBACKS :

- GREAT NUMBER OF OPTICAL CORDS
- WRAP-AROUND TIME EVALUATION
- PROTOCOL 629 APPLICATION TO BE EXAMINED



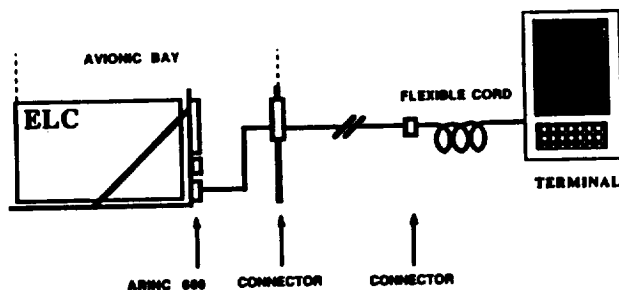
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OPTICAL TECHNOLOGY

ELECTRONIC LIBRARY SYSTEM



16 GAUGE OPTICAL FERRULES IN

- ➡ ARINC 600 CONNECTOR
- ➡ MULTIWAY CONNECTORS IN LINE

SINGLEWAY CABLE

- ➡ TIGHT STRUCTURE
- ➡ 100/140 μ m FIBER

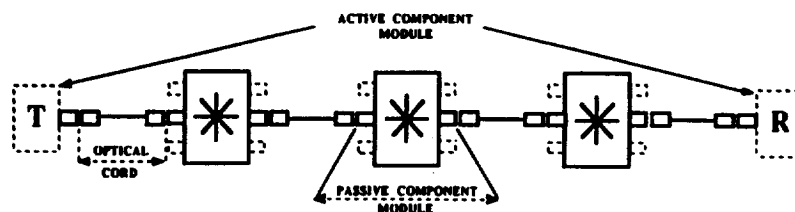
USE OF LED AS TRANSMITTER AND PIN AS RECEIVER

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INSTALLATION OF FIBER OPTIC COMPONENTS

MODULARITY APPROACH

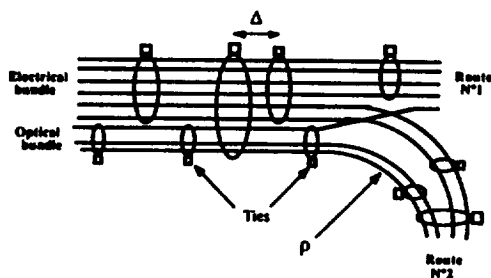


- ⇒ OPTICAL COMPONENTS EQUIPPED WITH FERRULES
- ⇒ EACH ELEMENT IS EASILY TESTED AND REPLACEABLE

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OPTICAL CABLES INSTALLATION



- ⇒ BUNDLE MAKE UP OF OPTICAL CORDS
- ⇒ LOW CURVATURE RADIUS: $\rho = 15 \text{ mm}$ MINIMUM
- ⇒ HIGH TENSILE STRENGTH (BETTER THAN AN ELECTRICAL CABLE)

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SENSORS (1)

AS AIRCRAFT MANUFACTURER, AEROSPATIALE NEEDS :

- Performant and reliable sensors.
- Low weight, low consumption sensors.
- Low price sensors.
- * For to-day functions : Anemo-baro metry
Inertia
Radio navigation
...
- * For new functions :
 - Optical sensing.
 - Windshear forecasting.
 - Ground collision avoidance.
 - Icing forecasting ?
 - Storm detection ??



SENSORS (2)

AS AIRCRAFT MANUFACTURER, AEROSPATIALE :

- Is not a sensor manufacturer.

BUT

- Issues requirements.
- Promotes architectures :
 - Ex : ADIRS for A320
- Helps sensor manufacturers to flight test new designs :
 - Ex : HONEYWELL GPS on A310 in 1988⁷ (?)
SEXTANT laser airdata computer.
(As flight test equipment) on A340.



SENSORS (3)

PRESENT REQUIREMENTS :

- Simpler anemo-baro sensing equipment :
 - *Candidate solutions :*
 - Multiple function probes with smart capability could provide side slip angle
 - Laser airdata system
- Cheaper inertial sensors :
 - *Candidate solutions :*
 - Fiber optic gyro (fog) or other technology
 - Use of fault tolerant concept to minimize the number of units
- Better GPS integrity :
 - *Candidate solutions :*
 - CE - GPS



SENSORS (4)

CE - GPS :

- European program using INMARSAT satellites.
- Under faisability study phase between :
 - CNES
 - ALCATEL (ground and air segment)
 - AEROSPATIALE (user segment)
- Goals :
 - To provide a second, independant satellite network (availability)
 - to detect any failure within 10 sec. max. (integrity).



SENSORS (5)

SENSORS FOR NEW FUNCTIONS

- Optical sensors.
- Windshear forecasting :
 - Radar ?
 - Laser anemo barometry ?
 - Other ??
- Ground collision avoidance (under study within EUROCAE).
- Storm detection ?
- Icing forecasting ??



DATA NETWORK

- Candidate functions and/or architectures are numerous.
 - AEROSPATIALE fully supports ARINC 629 bus...
and its "CP" protocol.
 - AEROSPATIALE favors ARINC 659 bus...
and requires quickly all data as public.
 - AEROSPATIALE has concerns about "FDDI" for today applications (mainly ELS
for A340).
- ⇒ Networking is a new technic for avionics industry and there is not yet a big
expertise
- ⇒ recommended methodology to choose a solution, to manage it, to certify it
should be usefull.

*Sextant Avionique
Corporate Headquarters
5/7, rue Jeanne Braconnier
92366 Meudon-la-Forêt
Cedex - France
Telephone: (33-1) 46 29 88 00
Telefax: (33-1) 40 94 02 51*

1.0 Date of Visit:

June 19, 1991

2.0 Panel Members:

Daniel Martinec
Robert Baumbick
Monica Mayton
Ellis Hitt
Joseph Traybar
Cornelius Leondes
Joseph Schwind
Cary Spitzer
Ramon DePaula
Chuck Homolka
Alan Angleman

3.0 Principal Contacts at Facility:

Jean-Louis Moraud

Air and Space Program Director (presented an introduction to the panel)

Bruno Messie

Director, International Business Development (presented the only briefing to the panel)

Daniel Giroux

Business Development Director Air Transport

4.0 Facility Overview and Organization

Sextant Avionique was formed on July 12, 1989 through the joining of the Aerospatiale subsidiaries Crouzet, Eas, and Sfena with the Avionics Division of Thomson-CSF. The ownership of Sextant Avionique is divided between Thomson-CSF/Aerospatiale (54%) and public ownership (46%). Present rankings place Sextant Avionique as one of the major avionics companies in Europe and in the international marketplace. Currently, Sextant Avionique has offices and facilities in France. Table A.4-1 provides the addresses of these facilities. Plans are for a new subsidiary in Miami, Florida, to be fully operational by the end of 1991. This subsidiary is dedicated to the maintenance of Sextant Avionique equipment and systems in service in the United States, marketing and business development, and sales of standard products.

Sextant Avionique is divided into two branches:

- Aerospace and Defense (ASD)
- Component and Industrial Systems (CSI)

The ASD branch contains six divisions. These divisions are:

- Flight Control Systems
- Displays and Interfaces
- Navigation Systems
- Flight Instruments
- Space
- Automatic Testing

The percentage of 1989 total sales for each of these divisions is as follows:

- Flight Control Systems - 31%
- Displays and Interfaces - 26%
- Navigation Systems - 12%

- Flight Instruments - 16%
- Space - 6%
- Automatic Testing - 5%
- Miscellaneous - 5%

Domestic sales accounted for 47% and 45%, respectively, of 1989 and 1990 sales. Indirect exports accounted for 31% of sales for both 1989 and 1990. Direct exports accounted for 22% of sales in 1989 and 24% in 1990. Sixty-three percent of 1989 sales went to the civil market and the remaining 37% to the military market. In 1990, 40% of sales were to the commercial aviation market, and 30% went to the military aviation market. The 30% military figure includes helicopters (9%), missiles/space (8%), automatic test (4%), and miscellaneous (9%).

Sales for 1989 totaled \$1 billion. ASD was responsible for \$690 million and CSI brought in the remaining \$310 million. Sales in 1990 increased to \$1.118 billion, with ASD responsible for \$841 million and CSI responsible for the remaining \$277 million.

In 1989, Sextant Avionique employed 9,850 people, with 6,050 employees in ASD and 3,800 employees in CSI. In 1990, the work force declined to 9,150 employees, with 6,100 in ASD and 3,050 in CSI.

5.0 Avionics R&D Programs

5.1 Display Systems and Interface Division

The Display Systems and Interface (DVI) Division has been designing and producing airborne display systems for both commercial and military aircraft for over 25 years, delivering 7,000 units over the last 12 years. In 1989, this division earned over \$270 million in 1989 with 900 employees. DVI

Table A.4-1. Sextant Avionique Offices and Facilities in France

<p>Corporate Headquarters 5/7, rue Jeanne Braconnier 92366 Meudon-la-Forêt Cedex - France Tel: (33-1) 46 29 88 00 Telex: SXT 631 155 F Fax: (33-1) 40 94 02 51</p>	<p>Orly Zone Ateliers Generaux Orly Bat. 659 Orly Sud No. 306 94544 Orly Aerogare Cedex - France Tel: (33-1) 46 87 21 21 Telex: 265 549 Fax: (33-1) 46 86 27 64</p>
<p>Bordeaux - Le Haillan Facility B.P.91 33166 Saint-Medard-en-Jalles Cedex - France Tel: (33-1) 56 34 70 00 Telex: SXT 616 780 F Fax: (33) 56 34 70 04</p>	<p>Valence 25, rue Jules Vadrines 26027 Valence Cedex - France Tel: (33) 75 79 85 11 Telex: 345 807 Fax: (33-1) 75 55 22 50</p>
<p>Chatelleraut 40, rue de la Brelandiere B.P. 128 86101 Chatelleraut Cedex - France Tel: (33) 49 93 74 00 Telex: 790 171 Fax: (33) 49 93 15 36</p>	<p>Velizy Aerodrome de Villacoublay B.P. 59 78141 Velizy-Villacoublay Cedex - France Tel: (33-1) 46 30 23 85 Telex: 260 046 Fax: (33-1) 46 32 85 96</p>
<p>Conflans J.A. Des Boutries B.P. 207 78703 Conflans Sainte Honorine - France Tel: (34) 90 84 00 Telex: 699 486 F Fax: (34) 90 84 84</p>	<p>Vendome Facility Societe Vendomoise d'Avionique (SVA) 41100 Vendome - France Tel: (33) 54 77 01 85 Telex: 751 381 Fax: (33) 54 72 24 04</p>

prides itself on its MMI technology. Sextant Avionique's DVI technological development efforts are multifaceted in nature and have been categorized into the following areas:

- Optics - HUD, HLD/HMD
- CRT Multifunction Displays Technology
- Flat Panel LCD Technology

5.1.1 Optics

Sextant Avionique's work in optics receives both military and corporate sponsorship. Sextant Avionique is currently producing the following HUD types:

- VEH110
- VEH120
- VEH130
- VEH3020
- SHUD (Smart HUD - current equipment on the Mirage F1CR)
- OHU Airbus
- VEM130
- VH100
- T100

Work is also being done on HLDs for aircraft pilots, applicable to the Rafale, and HLDs for helicopter pilots, applicable to the Tiger.

Sextant Avionique is also known for their HUD/HLD combined subsystem operating in the Mirage 2000-5. The HUD/HLD system combines a classical optical or holographic HUD (designated VEM130) with a HLD focused at infinity (designated TMM 1410). This HUD/HLD system allows the pilot to concentrate his view outside the cockpit, on the HUD symbology (focused at infinity) and on the HLD symbology inside the cockpit (also focused at infinity) without having to refocus his eyes. This reduces pilot workload, increases situational

awareness, and generally increases mission effectiveness.

Color HUDs are not yet common in fighter or commercial aircraft. The color displays at Sextant Avionique consist of the same basic technologies as their HUDs. Indications are that Sextant Avionique either has, or is working on, a color HUD, and perhaps a color HMD.

5.1.2 CRT Multifunction Display Technology

Sextant Avionique purchases CRTs from a Japanese company it declined to identify. No indication was given of either a possible R&D effort by Sextant Avionique in the area of CRTs or a possible purchasing arrangement with any country other than Japan.

Sextant Avionique's CRT multifunction displays (MFDs) can be found on the A320 Airbus, which has six CRT MFDs per aircraft, and the Super Puma helicopter, which has four CRT MFDs per aircraft.

5.1.3 Flat Panel LCD Technology

Sextant Avionique and Thomson Consumer Electronics jointly own Thomson-LCD, the company that hosts Sextant Avionique's flat panel LCD technology programs. Sponsorship of Thomson-LCD includes corporate ownership, the French Ministry of Industry (MOI)/Ministry of Defense (MOD), and the European Economic Community (EEC).

In 1986, GE licensed its LCD technology to Thomson-CSF. This exclusive arrangement was expanded in 1987 to include a joint LCD cell factory in France. One year later, GE decided to leave the LCD business entirely, and, in 1989, GE sold

Thomson/Sextant the worldwide rights to their LCD technology. Since 1990, GE has supported ongoing programs and a pilot-line transfer to Thomson-LCD's newly built plant in Grenoble, France.

Sextant Avionique is committed to several major European LCD programs, including multi-function LCDs for the Advanced Multi-role Fighter Aircraft, the Franco-German Tiger Attack Helicopter, and the European Hermes Space Shuttle. Several candidate U.S. programs include the Air Force Advanced Tactical Fighter, the Army Light Helicopter, the Air Force C-130/C-141 cockpit upgrade, fixed-wing and rotary-wing aircraft retrofits, and a possible space shuttle retrofit.

Table A.4-2 shows several Sextant Avionique LCD technology programs, display aspect ratio formats, and proposed production schedules.

In more general terms, Sextant Avionique has several basic goals for its future. Sextant Avionique plans to eventually position itself as the world's leading supplier of LCD cockpit displays, while continuing to benefit from Thomson's Consumer Electronics consumer industrial bases. Sextant Avionique hopes to continue development efforts to maintain and possibly expand General Electric military LCD technology, thereby increasing the span of their lead over Europe. LCD technology program goals involving the United States, for example, include providing the U.S. market with the highest-performance, lowest-risk LCD product, so that Sextant Avionique becomes recognized in the United States as a credible and dependable LCD source. Sextant Avionique envisions extensive, long-term cooperative business arrangements with U.S. industry.

For commercial aircraft, Sextant Avionique produces the LCD 66. This product is a high-

resolution, full-color multimode LCD using a 6"×6" active matrix. Sextant Avionique claims this LCD can display images for a variety of applications, including Electronic Flight Instruments System (EFIS), Electronic Centralized Aircraft Monitoring (ECAM), weather radar, Electronic Library System (ELS), video image or cartography mapping/zooming, aircraft camera system monitoring, and personal passenger visualization. The LCD 66 weighs about 8 kg with dimensions of 7.5"×7.5"×10". Useful screen area is 6"×6"; resolution is 92 dpi, lateral visibility limit is 54°, and it has a multimode capability, with stroke for symbology and raster for video. The power supply for the LCD 66 is 100 Vdc, and power consumption is 120 W or less.

The funding commitment to Thomson-LCD is \$50 million over 3 years and will originate from the owners (Sextant Avionique and Thomson Consumer Electronics), the MOI/MOD, and the EEC. The staff supporting LCD production at Thomson-LCD's Grenoble facility numbers approximately 60.

The construction of a 50,000 ft² LCD manufacturing plant was completed in June 1990 by Thomson-LCD in Grenoble, France. Installation of the factory equipment took from April to September of 1990, though the process start-up began in July of 1990. In December of 1990, LCD cells up to 6.25"×6.25" were being produced. Beginning in 1991, the Grenoble facility obtained the capacity for LCD cells up to 10"×10". Plant capacity is between 6,000 and 7,000 LCD cells per year.

5.2 Flight Control Systems Division

The Flight Control Systems Division (FCSD) has been designing and producing flight control systems for both commercial and military aircraft for over 25 years, delivering 18,000 computers, mainly digital, over the last 15 years.

**Table A4-1. Sextant Avionique Display Format (Aspect Ratio)
LCD Technology Program Schedule**

Program	Display Format (Aspect Ratio)	A/C First Flight	A/C Production Start
Rafale - Advanced Combat A/C (Dassault)	5 × 5	May 1991	1994
HAP/HAC - Armed Helicopter	6 × 6	Late 1991	1996
Hermes Space Shuttle	6 × 6	1998	--
C-130/C-141 Military Transport	6 × 8	Late 1992	Late 1993

In 1990, this Division earned over 265 million U.S. dollars with 870 employees. FCSD prides itself on its know-how on critical systems and development methodology.

Historically, FCSD pioneered the digital AUTOLAND CAT III A and B functions by developing CAT III B Autopilot on A300-600 and A310 aircraft, after designing and certifying an analog CAT III A Autopilot on A300 aircraft. It is currently in charge of developing the A330/A340 automatic flight system.

FCSD expanded its activity (mainly critical systems related) on A320/A321 aircraft, and further on A340/A330 aircraft with the following systems:

A320/A321

- Flight management and guidance computers (in cooperation with Honeywell), flight control unit, multipurpose control and display unit
- Fly-by-wire computers (SEC and ELAC)

- Maintenance computers
- Smoke-detection system (in cooperation with Cerberus Guinard)
- Fuel quantity measurement (in cooperation with BF Goodrich)
- Radio management

A330/A340

- Flight management guidance and envelope computers (in cooperation with Honeywell), flight control unit, multipurpose control and display unit
- Fly-by-wire computers (FCSC and FCDC)
- Maintenance computers (in cooperation with Aerospatiale)
- Smoke-detection system (in cooperation with Cerberus Guinard)
- Fuel control and management systems (in cooperation with BF Goodrich)

-
- Radio management
 - On-board printer

FCSD is currently developing and proposing to the market place an ELS suitable for both OEM and retrofit use. FCSD has recently been awarded the B-777 contract by Boeing for a full format printer that has graphics capabilities and is suitable for ELS interconnections.

FCSD development methods rely heavily on software development tools designed to develop critical software according to DO178 standards. These tools, named GALA, GALI, and PALAS, are approved by the airworthiness authorities to be used to develop critical software.

GALA and GALI are high-level graphics tools that automatically generate executable codes from the aircraft manufacturer specification. PALAS is an automatic software configuration management tool.

These tools have proven to be fully efficient on A320 and A340 aircraft development programs.

Sextant Avionique designs and produces flight control, flight management, and mission support systems. These systems make use of digital computers and interface with integrated maintenance systems, which, in turn, can provide several new functions, including automatic approach and landing and flight management at low altitude with the AP/FD Series 800. A specific 10-year Sextant Avionique effort has resulted in an interface with primary control systems via the flight path computer.

5.3 Miscellaneous Programs

Sextant Avionique is also involved in several other areas of avionics research and development. Most notably, Sextant Avionique is sponsoring research in the following:

Heading and Attitude Gyros. Sextant Avionique's inertial AHRS uses a hybrid of inertial/magnetic, heading/air-data measurement systems to ensure optimal primary reference system performance. The primary reference system chosen to complement the Totem 200 INS for the modernization of the TRANSALL is the Cirrus 1600.

Inertial Navigation. Sextant Avionique has 15 years' experience in the area of inertial navigation. Their Totem 200 laser gyro INS has been chosen for the TRANSALL upgrade.

Integrated Navigation and Mission Management Computers. The integrated navigation and mission management computer for Sextant Avionique's TRANSALL C 160R system is the integrated, modular 2 GEMINI 10. This system utilizes LCD technology.

Long-Range Navigation Systems. Sextant Avionique claims a significant lead in microelectronic integration, as evidenced by their highly compact and modular 5-channel GPS receivers (produced in both standard C/A-code and high-precision P-code versions). Sextant Avionique's NS 100P has been selected for the Mirage 2000D and for the Rafale.

Sextant Avionique is also involved with long-range navigation via low-frequency ground stations. Their OMEGA system is fitted to the N262, the TRANSALL, and the Falcon (French Air Force transport aircraft), and the ATL1, the Alize, and the Guardian (French Navy maritime patrol aircraft).

Flight Instrument Technology. Sextant Avionique produces a variety of flight instruments for combat and transport aircraft, including cockpit instruments, related sensors, and probes. Cockpit instruments are available in the traditional electromechanical configuration as well as the new flat panel LCDs, known as flat panel instruments (FPI). The FPIs provide a multifunction capability, thereby reducing instrument clutter in the cockpit.

Several of Sextant Avionique's newer products include: Permanent standby instruments (PSI) (currently in use on the Rafale), permanent standby visual systems (PSV), integrated flight control instrumentation, and multifunction probes. Sextant Avionique's newest multifunction probe has been selected for use on the Rafale and the EFA.

6.0 Non-Avionics Areas of Endeavor

Sextant Avionique's second major activity is their CSI branch, which generates approximately one-third of the company's revenues. The CSI branch consists of three divisions: Automation Components, Electric Appliance Components, and Terminals and Systems.

The Automation Components Division is a high-capacity industrial unit, mass-producing several products including miniature switches and aeronautical circuit breakers. Sextant Avionique's remote control contact breakers were selected for the Airbus A330/340 program. Sextant Avionique's DC motors, in both synchronous and stepper versions, affect the office automation, automatic distribution, medical, and automobile markets. Products for the electronic control sector include time-delay relays and fiber-optic optoelectronic

sensors. Sextant Avionique also provides pneumatic control equipment to the textile and automobile industries, with two-thirds of these contracts in export markets. The Automation Components Division has a wide-scale distribution network, with 12 subsidiaries outside of France.

Sextant Avionique's Electric Appliance Components Division ranks first among European producers of several types of programmers for washing machines, dishwashers, and clothes dryers. The types of programmers available include:

- Electromechanical
- Integrated connection systems
- Hybrid electronic-mechanical systems

Most major European appliance brands use these Sextant Avionique programmers.

As of 1989, the Terminals and Systems Division was responsible for three business sectors:

- Electronic payment (portable bank terminals)
- Automatic fare collection (subway and bus transportation; magnetic systems for urban buses)
- Public telephones (cooperative effort with France Telecom to develop a card-operated "publiphone" network)

The management structure of Sextant Avionique is shown in Figure A.4-1, and the operating and financial highlights for Sextant Avionique are presented in Figure A.4-2.

Management
Jean Ségui,
Chairman and CEO
Jean Monfort,
Chief Operating Officer

Corporate Divisions

Human Resources
Max Matta

Finance
Lucien Arbel

Legal Affairs
Patrick Gourdeau

Management Control
Jean-Paul Lorinet

Strategy & Planning
Gérard Delalande

Information Systems
Christian Lefèvre

Communications
Jean-Claude Salvinien

Corporate Divisions
(Aerospace & Defense
Branch)

Marketing & Programs
François Péguillan

Research & Development
Claude Vuillemin

Manufacturing
Vincent Redondo

Quality Assurance
Jean-Jacques Gourden

Customer and
Product Support
Louis Sangouard

Product Divisions
(Aerospace & Defense
Branch)

Flight Control Systems
Jacques Bonnet

Display Systems &
Interfaces
Jean-Paul Lepeyre

Navigation Systems
Daniel Kholer

Flight Instruments
Guy Baruchel

Space
Henri Col

Automatic Test
Gérard Chalimon

Industrial
Components

Manuel Fuentes

Figure A.4-1. Management Structure of Sextant Avionique

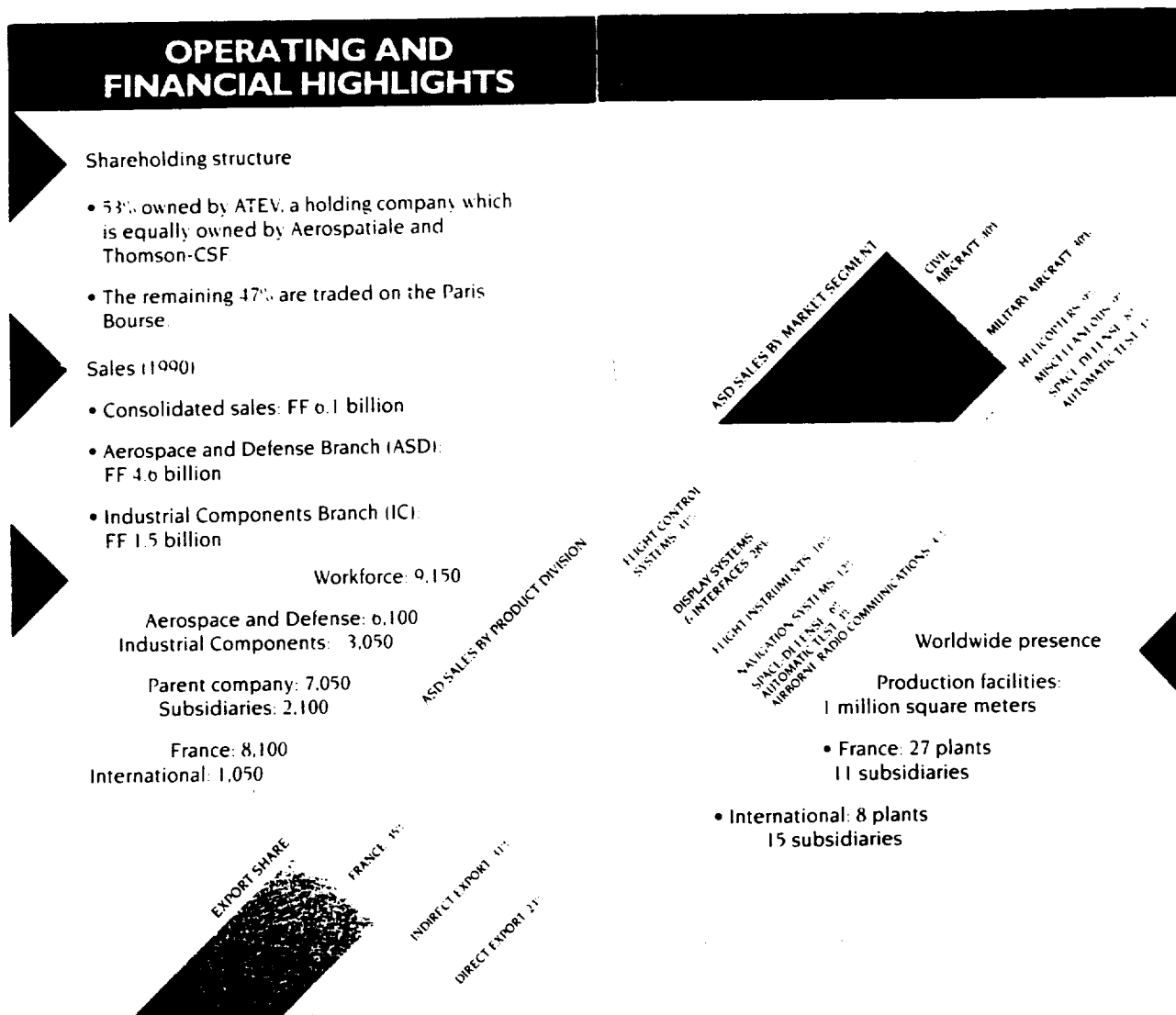


Figure A.4-2. Operating and Financial Highlights for Sextant Avionique

*Office National D'Etudes et De Recherches
Aerospatiales (ONERA)
29, Avenue de la Division Leclerc
Châtillon (Hauts-de-Seine)
France*

1.0 Date of Visit: 20 June 1991

2.0 Panel Members: Daniel Martinec
Robert Baumbick
Monica Mayton
Ellis Hitt
Joseph Traybar
Joseph Schwind
Cary Spitzer
Ramon DePaula
Charles Homolka
Alan Angleman

3.0 Principal Contacts at Facility:

J. A. Appel
J. M. Boutry
B. Vaizan
G. Bobillo
Jean Paul Ovarlez

Radar Division
Airborne Systems
Radar Division
Signature Control

4.0 Facility Overview and Organization

ONERA was founded in 1946 as a scientific and technical public company under the Ministry of Defense, General Delegate for Armament (DGA). The mission of this institution is to develop, orient, and coordinate research in the field of aeronautics.

In 1963, the charter for ONERA was modified in response to two factors. The first was the advent of space research and the second was the reorganization of the Defense Ministry, with the creation of the Directorate for Research and Testing Facilities (DRME), now known as the Directorate of Armament Research Studies and Techniques (DRET), whose coordinating and orienting action was placed in the broader framework of the defense field as a whole. ONERA, in connection with CNES (the French National Space Agency), worked on research and experimental projects in the space field.

In the decentralization of the National Center for Superior Aeronautics and Space (ENSAE), ONERA, in 1968, took over the CERT (Toulouse Research Center) with its staff of 240. The Lille Institute of Fluid Mechanics (IMFL), a research institute with a staff of 100, was incorporated as a result of a 1983 decree. In 1984, ONERA's primary mission of aerospace research and technical support for industry was reaffirmed. A decree of January 11, 1984, restated this mission by asserting the role of ONERA in the definition and development of computational facilities, the promotion of research in and out of the aerospace field, and in the training of researchers.

The ONERA Chairman is responsible for the general management of the CERT and is assisted by the High Scientific and Technical Committee. The Chairman prepares the R&D and technical investment programs within general guidelines set

by the Minister of High Scientific Committee. The planning of programs is done in conjunction with the DRET Director and other government agencies and with Direction Generale de l'Aviation Civile (General Directorate for Civil Aviation, the French equivalent of the FAA or the British CAA). The final approval of programs is given by the Ministry of Defense. The Chairman is also responsible for the preparation of ONERA budget.

The organizational structure of ONERA is as follows:

ONERA's General Scientific Director is responsible for defining ONERA's long-range scientific policy and for ensuring insertion of the programs in the framework of this policy. A General Technical Director (GTD) coordinates the technical activities of all the operational departments. The GTD is assisted by a Director for Military Applications, a Director for Programs and Infrastructure, and a Director for Aeronautical Applications. A General Inspector inspects programs and advises and coordinates all international scientific and technical relations. The director of the Modane-Avrieux and Le Fauga-Mauzac facilities area operates under the authority of the Director of Large Testing Facilities.

In the Ile-de-France region, Châtillon houses the headquarters and main laboratories. Wind tunnel research is done at Chalais Meudon, and the energy research facility is located at Palaiseau. Large industrial wind tunnels are located at the Modane-Avrieux facility, CERT and Le Fauga-Mauzac Test Center. Le Fauga-Mauzac will receive new and larger test facilities for research in aerodynamics and propulsion. All three facilities are located in Toulouse. Lastly, flight mechanics and structural mechanics facilities are located in Lille.

As of 1989, ONERA employed 2,119 people, including the employees of CERT and IMFL. This included 986 engineers and managers; 717 draftsmen, supervisors, and technicians; 115 workers; and 301 clerical staff, dispersed as follows:

Discipline	No. of People
Systems	180
Aerodynamics	184
Energy	181
Materials	107
General Physics	155
Structures	114
Large Test Facilities	322
Computer Facilities (CERT & IMFL)	57
Technical Staff	217
Executive & Administrative	248
CERT	244
IMFL	110
TOTAL	2,119

By Plant	No. of People
Châtillon	1,068
Chalais-Meudon	252
Palaiseau	159
Modane-Avrieux	217
Le Fauga-Mauzac	69
CERT	244
IMFL	110
TOTAL	2,119

Net Operating Funds	Millions DM
Ministry of Defense Funding	371
Contracts	758
Other	9
TOTAL	1,138

Disbursements

Aircraft	341
Helicopters	57
Turbomachinery	125
Strategic, Tactical Missiles	387
Space	125
Non-Aerospace Studies	6
Multi-Purpose Studies	97
TOTAL	1,138

5.0 Avionics R&D Programs

The Aerodynamics work is divided into two major categories: fundamental aerodynamics and applied aerodynamics. The purpose of fundamental aerodynamics is to develop tools for predicting flows, from incompressible to hypersonic. The task is to generate computational codes that will solve the equations of fluid mechanics with different levels of approximations. For example, potential and Euler equations are used for inviscid flow and Navier-Stokes equations for viscous flow. The studies include strong interactions of flow with physical boundaries that can cause separation and shock-wave boundary-layer interactions for which both inviscid and viscous flow modeling is required.

In applied aerodynamics, work is focused on adapting the prediction methods derived through work in fundamental aerodynamics to specific problems of industry, and validating these methods through experiments. These studies include applications to airplanes, helicopters, missiles, and launchers.

Systems Department. In the Systems Department the fields of research include:

- Aerospace mechanics for analysis of aircraft and space missions

-
-
- Impact of thermophysical phenomena such as kinetic heating, damage, and icing on the performance of flight systems
 - Integration of new concepts in preliminary missile projects and their evaluation by ground and flight tests
 - Development of methods and hardware associated with processing antenna array information such as radar signature analysis (for stealth)
 - Design and testing of electro-optic systems
 - Data processing and image processing decision-making for system identification
 - Radar - detection, tracking, SAR, and ISAR imagery

Significant achievements recently demonstrated include the following:

- Resetting of navigation information in standoff missiles, a major measurement campaign relative to radar imagers, was successfully conducted in collaboration with industry.
- Various satellite constellations were analyzed and the advantage of associating a geostationary satellite with the constellation of the GPS to improve robustness was demonstrated.
- Successful demonstrations of non-intrusive instrumentation in the Modane S3 wind tunnel were conducted using the thermal response of a model subjected to a short laser pulse and infrared thermography.

This allowed mapping of convective heat transfer coefficients even in the presence of noise sources.

- A major effort was conducted on dedicated real-time radar signal processing.

Two different dedicated processors have been developed for the real-time signal processing of the radar RIAS. The first one, called TRIAS, is a digital processor that uses simplified arithmetic; the other one is an electro-optical device based on use of incoherent IR light and fixed-film masks, capable of about 2.10×10^{10} complex operations per second.

RIAS is an experimental air defense radar that allows simultaneous omnidirectional surveillance and tracking. It is a 4-D radar (range, Doppler, azimuth, and elevation) consisting in a sparse array of two concentric circles: one for emission and the other one for reception. The specificity of RIAS is the omnidirectional illumination of space at emission realized by use of decorrelated codes on each emitting device. VHF frequencies are used giving anti-stealth capability to the system. Bi-static tests are also conducted demonstrating the possibility of an aircraft flying in the RIAS range to locate itself and targets without emitting.

Other studies include over-the-horizon detection (NOSTRADAMUS), ground-to-air and air-to-ground signature analysis (BRAHMS and RAMSES) with the possibility of SAR and ISAR imaging in a diversity of frequencies (1.6 to 94 GHz) and polarizations.

Computer Science Department. The Computer Science Department is responsible both for implementing the central computation facilities and for

researching new computer architecture and applications of artificial intelligence techniques. The central computation facilities contain a Cray XMP 416 supercomputer. Work in the field of neural networks and research on characterization, comparison, and evaluation of an automatic learning system is under way.

6.0 Non-Avionics Areas of Endeavor

ONERA also conducts research in non-avionics areas as described here.

Structures Department. The Structures Department researches the behavior of structures in specific environments, characterizing the systems as "simple dynamic models" and "very complex multi-dimensional models," to study the high-modal frequencies and interactions between various orthogonal modes. Along with developing models of environments, the Structures Department is also

interested in developing methods to control certain structure characteristics.

Materials Department. The Materials Department conducts research on alloys for single-crystal blades, conventional powders for turbine disks, alloys derived from microcrystalline, methods to protect against high-temperature corrosion and oxidation, and thermal barriers. Additionally, materials research is looking into more durable lightweight materials for structures and engine components.

Physics Department. The Physics Department conducts research in five major areas: electronics and measurements, optics, quantum optics, acoustics, and electromagnetic environments.

The locations of the ONERA facilities are shown in Figure A.5-1, and the organizational structure of ONERA is shown in Figure A.5-2.

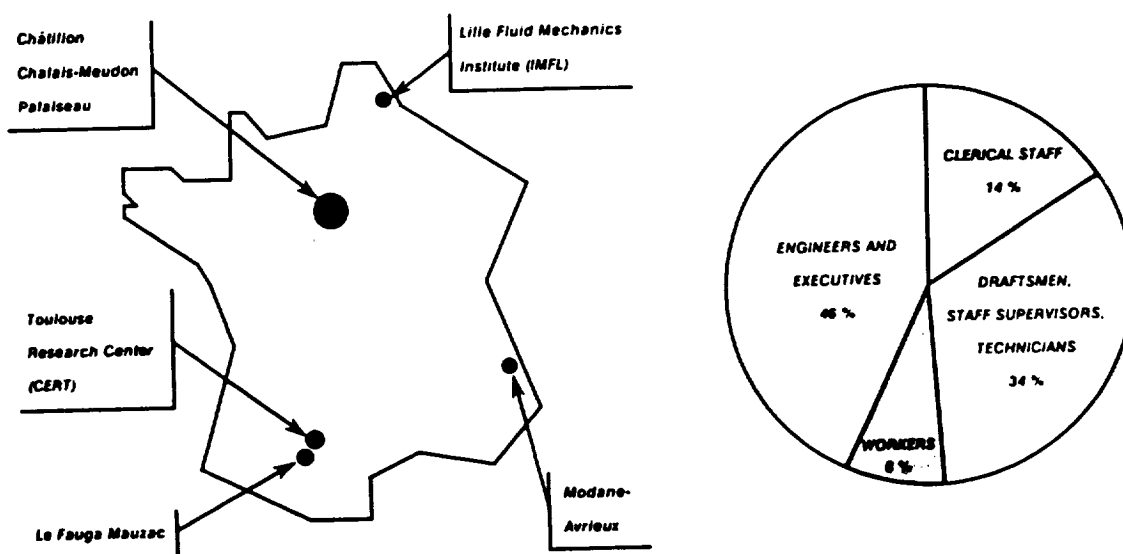


Figure A.5-1. Locations of ONERA Facilities

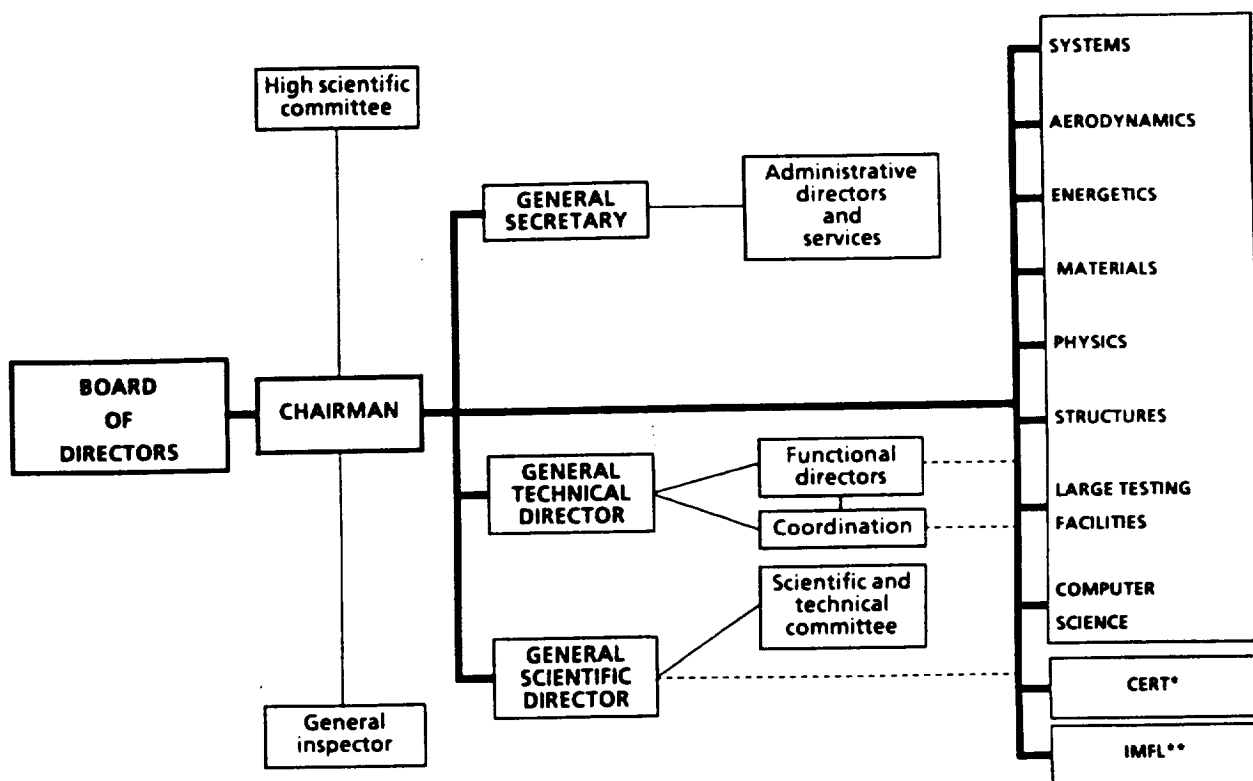


Figure A.5-2. Organizational Structure of ONERA

*General Electric Company Avionics Limited
Airport Works
Rochester Kent, England ME1 2XX
Telephone: Medway (0634) 844400
Telefax: (0634) 827332*

1.0 Date of Visit: 24 June 1991

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Monica Mayton
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Cary Spitzer
Ramon DePaula
Charles Homolka
Alan Angleman

3.0 Principal Contacts at Facility:

David Clews
Ian Stitt
Ray Dennis
Tom Hamill
Chris Bartlett
Cyd Sowler

4.0 Facility Overview and Organization

The General Electric Company plc (of England) is part of the GEC Marconi Group. Headquartered in Rochester, Kent, GEC Avionics Limited has 15 divisions and departments located in the United Kingdom. These include:

Airborne Display Division. Develops and produces all types of display systems for military aircraft and is a leading supplier worldwide of HUD systems.

Applied Physics Division. Supplies a range of military and civilian products that includes high-reliability neutron generators, ionization chambers, electron beam sources, gas lasers, and laser systems.

Aviation Service and Repair Division. Offers total integrated support for GEC Avionics' civil and military products.

Central Quality Department. Product assessment, development and NAMAS accredited testing services covering a wide range of national and international standards.

Combat Aircraft Controls Division. World leader in flight controls, with over 40 years experience, 20 of them in digital flight control.

Flight Controls Division. Markets a complete range of primary and secondary flight control systems for civil transport, military transport, helicopters, airships, and unmanned aircraft.

Guidance Systems Division. A leading supplier of attitude sensing, stabilization and navigation equipment for land, sea, and air applications.

Instrument Systems Division. Air data and stores management systems for helicopters and fixed-wing aircraft.

Maritime Aircraft Systems Division. Supplies a wide range of advanced sonobuoy and dipping sonar processing systems and tactical processors for maritime patrol aircraft and anti-submarine warfare helicopters.

Monitoring and Control Division. Responsible for monitoring and control systems for airframes and engines and for the oil industry. Also includes the Offshore Projects Group.

Power Conversion Systems Division. A leading supplier of custom-designed, high-reliability, severe-environment power supplies and power conversion equipment in operational service worldwide.

Recording Systems Division. Design and manufacture of recording systems for defense and commercial applications in harsh environments.

Support Equipment Systems Division. Automatic test equipment (ATE) for functional testing of digital and analogue equipment for factory, depot, and field use, including mobile applications.

Technology and Systems Research Laboratory. Investigates emerging technology and systems concepts applicable to all aspects of the company's business.

GEC Marconi Sensors and Avionics Research Laboratory. This laboratory is part of the GEC Marconi Research Centre at Great Baddow, which provides a central applied research and development resource for all GEC Marconi companies.

GEC Avionics also has subsidiary divisions located throughout the United States:

- GEC Avionics Inc, Atlanta, GA - Established in 1962, employs 300 people and maintains branch offices in Fort Worth, Los Angeles, Seattle and Dayton.
- Lear Astronics Corp., Santa Monica, CA - Designs and manufactures a wide range of military and civil avionics products.
- Developmental Sciences Corp., Ontario, CA - Offers a range of remotely piloted vehicles and unmanned aircraft avionics, extending to manned aircraft systems integration.

GEC Avionics has 70 companies worldwide with yearly sales of approximately \$15 billion. Approximately 65% of total sales are from exports. GEC Avionics is responsible for 55% of the United Kingdom's avionics equipment that is exported to foreign countries.

Within the field of avionics, GEC focuses primarily on cockpit and flight control. Multi-mode electronic agile radars are being pursued by another separate entity within GEC Marconi in partnership with Thompson-CSF.

5.0 Avionics R&D Programs

GEC Avionics is clearly at the forefront of the avionics industry. They supply major avionics equipment for the B-777, the ATF, the EFA, and other major aerospace systems. In all cases they were selected as the result of intense competition on the international scene.

5.1 Display Systems

GEC Avionics does significant work in the area of avionics displays. Cockpit display products include flight information displays and maps/route information displays.

Most notably among the GEC Avionics display systems is the HUD for the ATF, the result of five years of intensive research. It is currently the most advanced wide-angle HUD for fighter aircraft. It features a single flat combiner, which ensures maximum pilot visual clarity while preserving the degree of head freedom necessary to perform complex aircraft operations in the ATF itself.

The Knighthelm is a modular helmet-mounted, multi-mission display system which provides head tracking, day/night capabilities, and scan conversion. The field of view can be 30, 35, or 40 degrees with binocular vision.

The ALPHA system is a helmet-mounted aiming system. The ALPHA system can also provide inter-cockpit queuing. Sighting and queuing information is presented to the pilot by means of a high-brightness LED reticle relayed by a prism and reflected into the pilot's eye via a dichroic patch coating on the inner surface of the clear helmet visor.

CATS EYE is a unique aviators' night vision goggle. It provides full binocular night vision and is compatible with all HUDs. It has a 30° circular FOV, 25 mm eye relief, uses a third-generation image intensifier, and provides full color display compatibility.

The HUDWAC (HUD Weapons Aiming Computer) uses MIL-STD-1787 symbology and provides navigation, air-to-ground, and air-to-air

combat modes. Growth capability is available to all future avionics sensors that might be used for these missions. Modes provided include continuously computed impact mode (CCIP), dogfight mode (which combines missile and gun modes), and navigation. Six thousand of these systems have been installed in 25 different types of combat aircraft.

Currently, GEC Avionics provides a diffractive optics HUD with an IFOV of $30^\circ \times 18^\circ$ for such systems as the Low-Altitude Night Target Identification and Recognition Navigator (LANTIRN). While the LANTIRN HUD is not currently identified by the U.S. Air Force as a flight-critical item, it will in time become such due to the low-altitude terrain flight requirements. The Advanced Fighter Technology Integration (AFTI) HUD, supplied by GEC Avionics, is a conventional refractive optics system that provides a 25° TFOV and a $20^\circ \times 15^\circ$ IFOV. GEC Avionics is developing extremely large IFOV dual-capability HUDs through the use of diffractive optics to provide $40^\circ \times 30^\circ$ FOVs. Additionally, the trend is toward flight-critical HUDs in certain operational situations.

GEC Avionics has developed a control and display unit (CDU) that uses supertwist bi-refrangement LCD techniques to provide a high-contrast ratio with wide-angle viewing thus allowing a high degree of flexibility in cockpit locations. The CDU uses many different applications, including navigation and flight management systems, C^3I , moving map control, in-flight fault analysis, and weapons stores management.

5.2 Flight Control Systems

GEC Avionics has many programs concerning the research and development of flight control systems. These include:

Total Terrain-Avoidance Avionics (T^2A) Flight Control System. GEC Avionics has developed SPARTAN, a complete covert navigation and terrain-following TRN/TF avionics and flight control system. This system uses stored map and elevation data with flight profile information which fixes the aircraft's position and provides terrain-following capability for survivability. The SPARTAN system has been supplied for a major aerospace system under the world's first contract for a system of this kind.

B-777 Primary Flight Control System (PFCS). The PFCS features three identical channels and three dissimilar lanes using other channels. The dissimilar lanes use three different computer software/hardware systems designed by three different teams. Failure rate is reduced significantly as a result of this triple redundancy. Multiple voting planes are another feature. Extensive use is made of ASICs in order to reduce component count and thereby enhance reliability.

Primary Flight Computers (PFC). Each PFC receives pilot commands from a triplex ARINC 629 flight control databus as well as aircraft motion information from air data and inertial sensors. Control laws within the PFC calculate the optimum actuator demands based on pilot inputs and aircraft motion to provide safe, smooth control.

Advanced Digital Flight Control Systems. In advanced GEC Avionics digital flight control systems, extensive verification and validation of flight software is conducted by independent software teams in order to guard against residual software errors. All software is written to satisfy DO 178 Level 1 requirements, and

certain critical algorithms are subject to formal design and proof methodologies.

EFA Flight Control System. The EFA flight control system embodies many of the same comprehensive design approaches. It uses a network of microprocessors, higher-order software languages and advanced packaging techniques. The flight control system is designed for severe electromagnetic environments. Direct drive actuation interfaces and quadriplex inertial measurements are used.

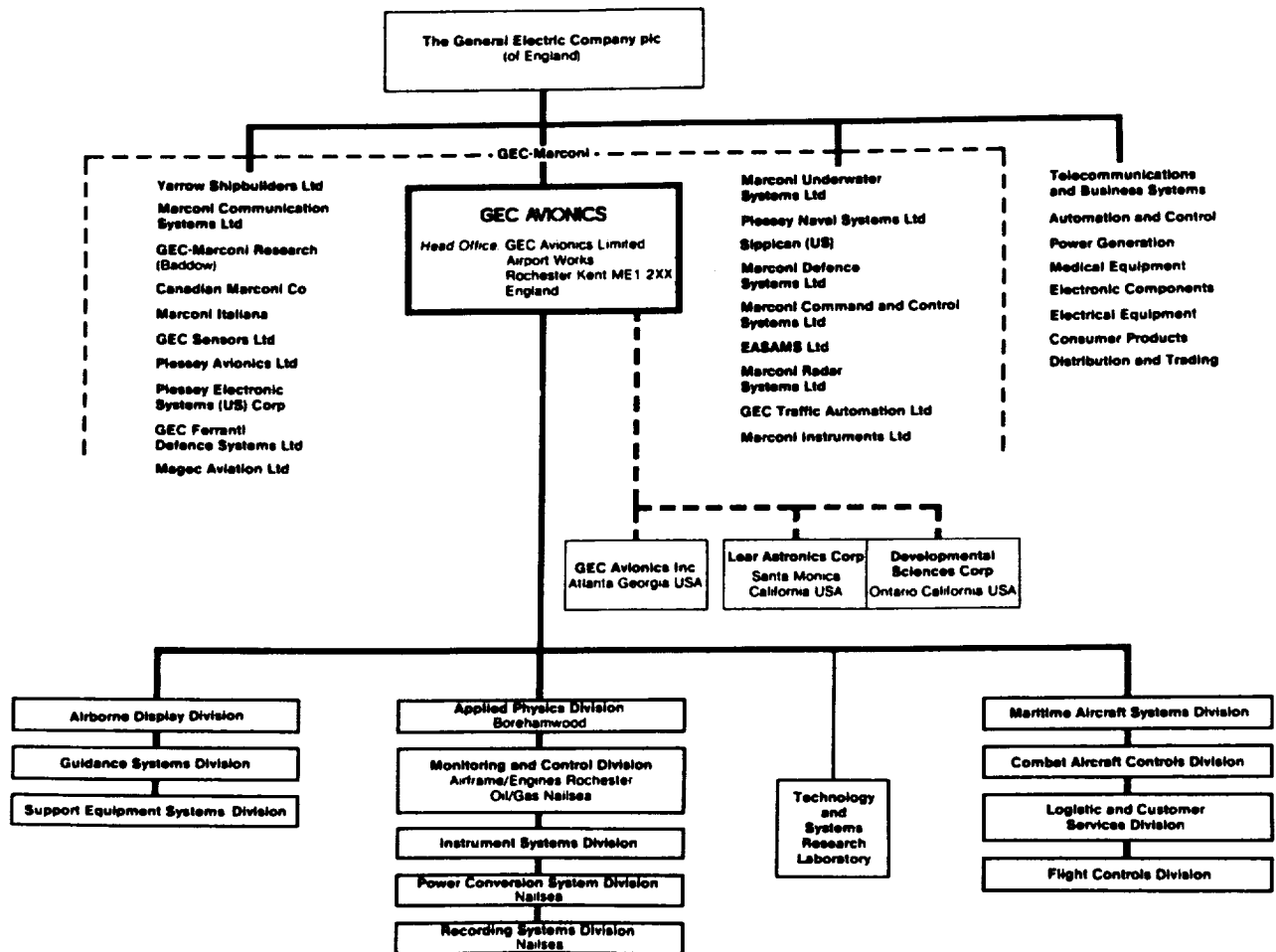
ATF Flight Control System. The ATF (YF-22A) flight control system is supplied by GEC, which is the strongest possible testimony to their preeminent capabilities in advanced flight control systems. It is a total FMS, and is evidently going to be the first advanced, fully deployed aerospace vehicle to use comprehensive integration of fuel, engine, flight, electrical, and other controls. In the ATF, the pilot's side-stick controller will provide the primary link between the pilot and the aircraft,

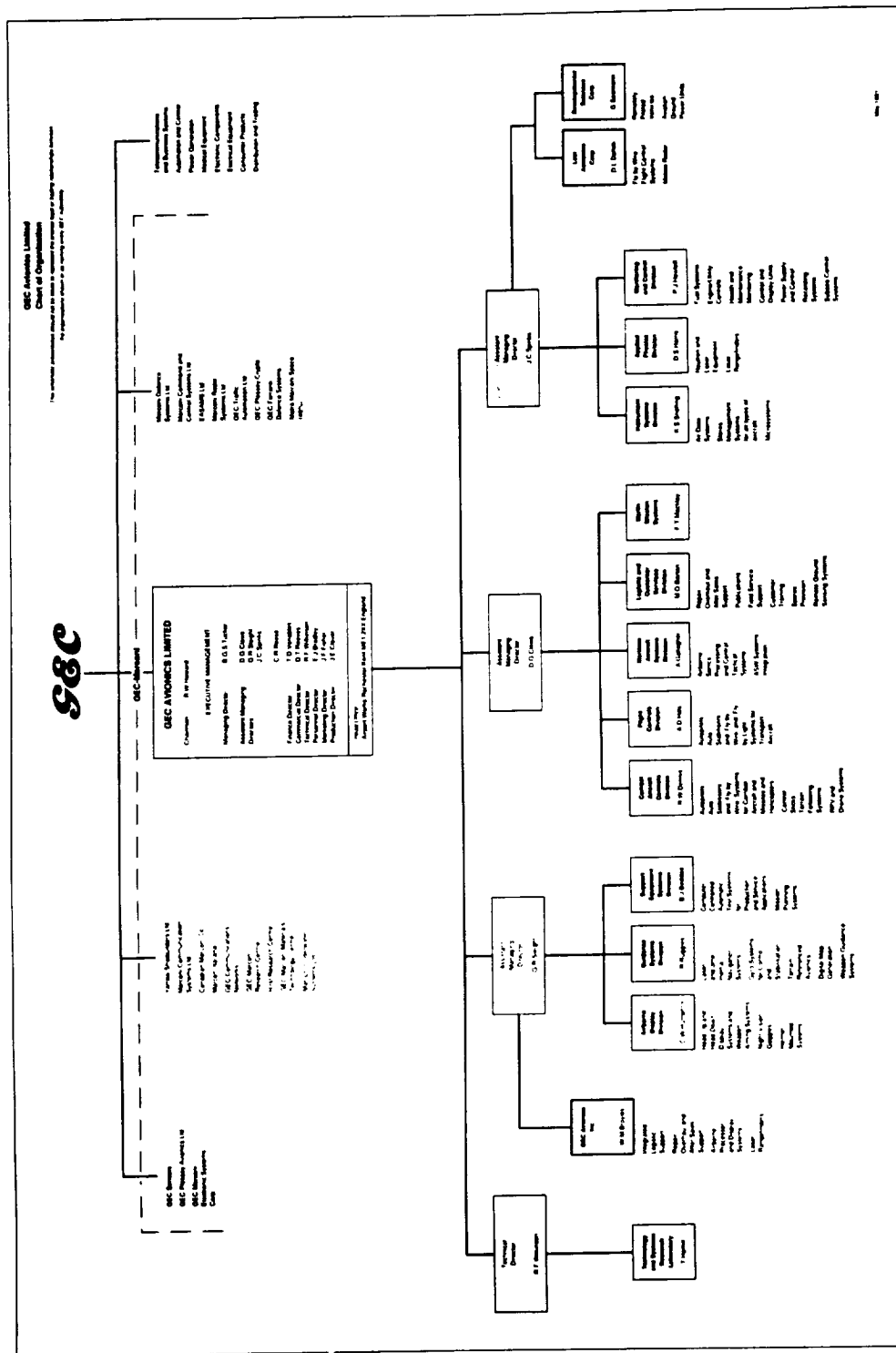
converting the pilot's control movements into the aircraft's fly-by-wire flight control system. Also, the FMS will integrate all the flight-critical and semi-flight-critical systems on the ATF, including the flight controls, hydraulics, and environmental control.

Engine Monitoring Unit. A significant element of GEC Avionics' capability is in propulsion and engine monitoring systems. Their engine monitoring unit (EMU) accepts data such as exhaust gas temperatures, fan speed, core speed, throttle angle, oil temperature, oil pressure, radio altimeter, air data, and other data.

Other technologies noted were airship fly-by-light control system efforts, solid-state flight data transducers, MIL-STD-1553 and STANAG 3910 bus analyzers, and comprehensive standard modular avionics repair and test system products.

Excerpts from the GEC briefing presented to the NASA panel are provided on pages A6-6 to A6-9.

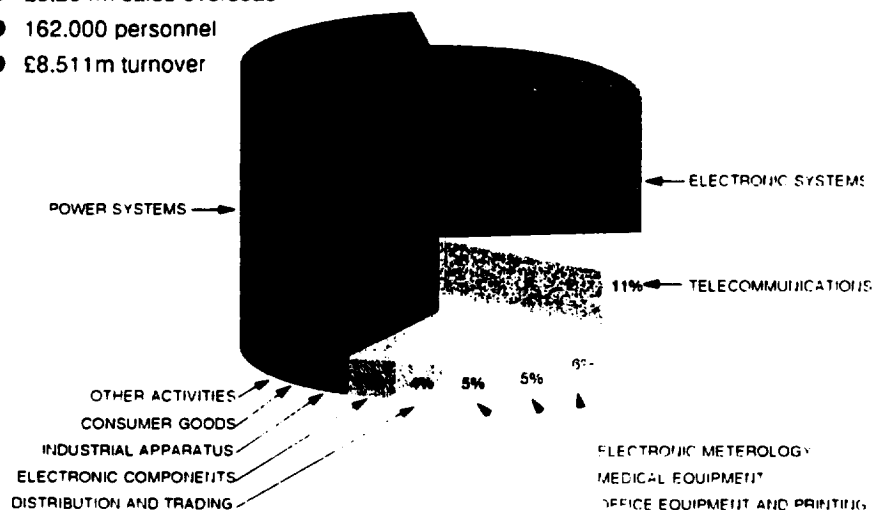




The General Electric Company

Areas of business (1989/90)

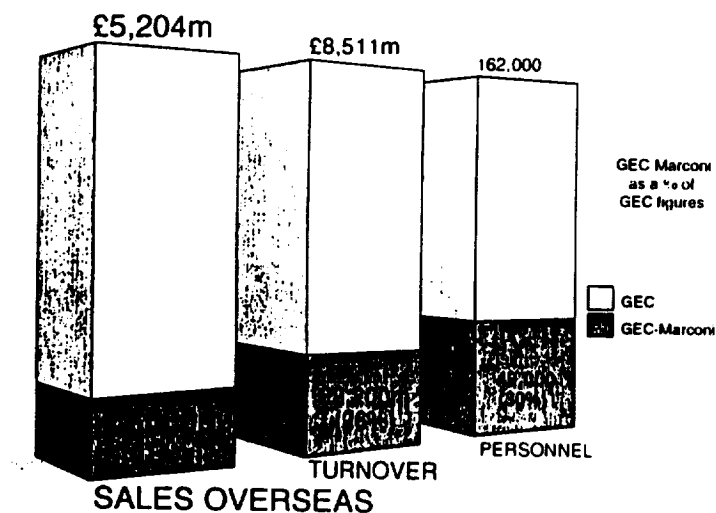
- Over 70 companies worldwide
- £5.204m sales overseas
- 162.000 personnel
- £8.511m turnover



GEC-Marconi in GEC (1989/90)

GEC Marconi

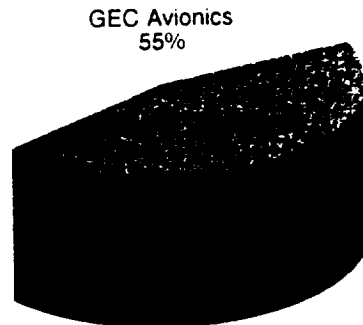
- 22 companies
- 75% defense, 25% civil



GEC AVIONICS

UK Avionics Exports (1989/90)

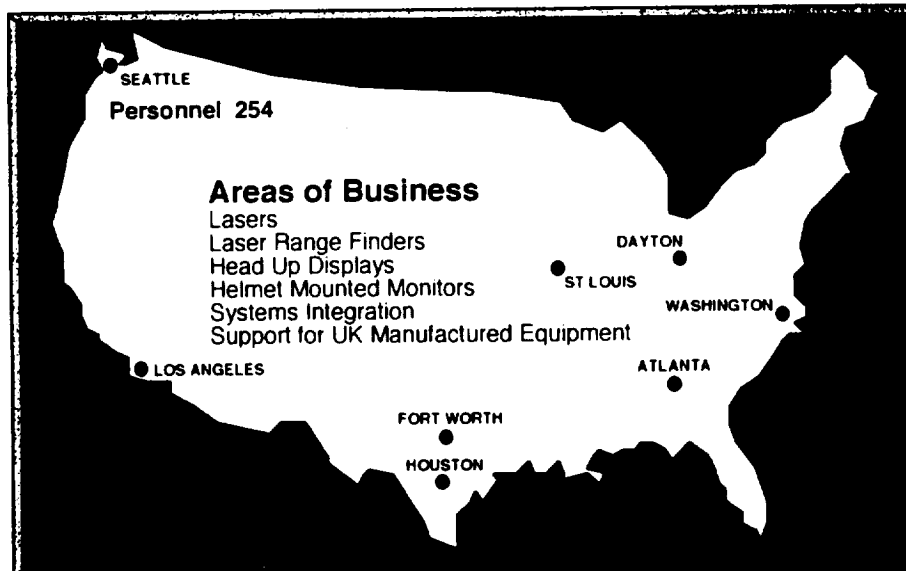
- Exports to over 70 countries



Percentage based on figures
published by the SBAC 10
and March 1990

GEC AVIONICS

GEC Avionics Incorporated (1989/90)



APPENDIX A7

SITE REPORTS

*Smiths Industries
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15 June 1991

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Ian Moir
John Weston
Dr. Dai Williams

Technical Executive (Corporate)
Engineering Executive

Engineering Manager, Avionic Control Systems Division

Divisional Engineering Manager, Flight Displays Systems Division
Systems Development Manager, Avionic Control Systems Division
Technical Director
Engineering Manager, Flight Deck Instrumentation

4.0 Facility Overview and Organization

Smiths Industries (SI) is a multi-business company with groups in medical, aerospace, and industrial areas. Worldwide, SI has 13,500 employees, 8,500 of which are in the Aerospace Group. SI has a worldwide turnover of £675 million, with the Aerospace Group having a £455 million turnover. The Aerospace Group does work in aerospace systems, land systems, and maritime systems. SI worldwide sales are 38% commercial and 62% military, with a customer sales breakdown as follows:

- North America - 62%
- United Kingdom - 17%
- Rest of Europe - 11%
- Rest of the world - 10%

Major customers for military avionics include Boeing, British Aerospace, Eurofighter/Eurojet, General Dynamics, Grumman, McDonnell Douglas, Panavia/Turbo-Union, Rolls Royce, the U.K. government, and the U.S. government. SI's single largest customer for military avionics is the U.S. government. Major commercial customers include: Airbus, Boeing, British Aerospace, McDonnell Douglas, and Rolls Royce. Table A.7-1 compares SI with other major avionics companies in the areas of military and civil sales.

The Smiths Industries Aerospace and Defence Systems (SIAD) operates six research, development and production centers in the United Kingdom. The six locations are:

- Cheltenham - flight control systems; electronic displays; flight management systems; gyros; flight deck and cockpit instruments and equipment; advanced digital systems; research and product technology primarily for the civil sector

Table A.7-1. Military versus Civil Sales

Company	Sales (£)	% Military	% Civil
Honeywell	1.0	40	60
Rockwell-Collins	0.9	40	60
GEC Avionics	0.8	70	30
Allied Signal	0.6	60	40
Smiths	0.4	62	38
Sextant Avionique	0.4	50	50
Deutsche Aerospace	0.3	80	20
Aeritalia	0.25	95	5
Thompson CSF	0.2	95	5
Litton	0.2	70	30
Lucas	0.2	50	30

- Basingstoke - engine controls (FADEC); fuel content measuring and indicating systems; radar altimeters; health and usage monitoring systems
- Putney - engine temperature measurement equipment (thermocouples and ignition systems); optical sensors
- Tewkesbury - Microcircuit engineering (MCE) development (large-scale custom integrated circuits)
- New Addington - helicopter instruments and systems
- Hainault - ship radar and navigational systems; sonars; air traffic control; fish finders; Admiralty charts

SI has five facilities in the United States located in the following cities:

- Grand Rapids, MI
- Florham Park, NJ

- Malvern, PA
- Clearwater, FL
- Stamford, CT

SI has other facilities located in Melbourne, Munich, Singapore, and Toulouse.

The Avionic Control Systems Division (ACSD) is responsible for the application of technology developed by other groups within SI. In 1990, ACSD sales were £42 million with 75% consisting of civil sales and the other 25%, military sales. The facility totals 110,000 ft² and currently employs 700 people. ACSD work includes the auto-land for the Trident, the autothrottle for the B-737, the flight management system for the A300/310, and the utilities management system for the AH-64 Apache.

5.0 Avionics R&D Programs

The European community Brite/Euram Aeronautics Research Funding for avionics is shown in Table A.7-2.

Table A.7-2. Brite/Euram Aeronautics Research Funding

Phases	Year	Funding
I	1990/1991	\$60 million ECU*
II	1992/1994	\$85 million ECU
III	1995 -	\$270 million ECU

*(European Currency Unit) 1 ECU approximately equals 0.7 £.

Brite/Euram is a trans-national competitive bidding program. The Phase I \$60 million ECU (\$71.4 million) is spread across approximately 20 projects. Phase II will involve SI's health and usage monitors, digital flight systems, data acquisition, and

flight decks. NOSCA is another SI project with Brite/Euram funding.

5.1 Flight Control Systems

ACSD flight control systems work includes the following projects:

- Auto-throttles
- Air data
- Para-visual directors
- Wing sweep actuators
- Vehicle and utilities management
- Stores and mission management
- Data management, including loading and recording
- Flight management, and air navigation
- Test equipment.

ACSD has developed a digital air data computer that uses rotating cylinder pressure transducers. A 500-FAD series digital air data computer capable of storing management system controls was produced for the B-737-300, -400, and -500.

ADSC has produced an enhanced flight management system for the A300-600 and A310. This flight system provides flight planning, navigation, performance optimization, flight production, and vertical and lateral guidance. The software used was developed with the CORAL 66 language and totals 600,000 words. A version of this system is on the E-6 aircraft.

Engineering products and development at the Avionic Control Systems Division include:

- B-777 electrical load management system
- Long Bow Apache electrical management system

-
- EH-101 automatic flight control system
 - EFA utilities control system, mission data loader/recorder bulk storage device, and digital interface unit

Also in development is a digital air data computer to be incorporated into the flight management systems of the E-6 and the A300/310. The B-737 auto-throttle continues in production. Development of mission management, armament control systems, and Harrier electrical equipment continues.

The para-visual display system is being used on the B-747 and the MD-11. A barber-pole rotating cylinder operates on the principle of parabolic vision using a motor tachometer. This system provides takeoff guidance. They are considering replacing this device with a solid-state LCD.

MCE at Tewkesbury, which developed the MIL-STD-1553B chip set in 1982, is developing data bus applications. They are also developing the DATAC/ARINC 629. They have performed bus traffic analysis and prefer the CP for file transmission. The demonstration/evaluation rigs were provided to Aerospatiale and British Aerospace. These activities are concluding.

This division is developing key technologies for a range of products, including integrated modular avionics with British Aerospace at Philton. They address integration issues, including hardware packaging to permit removal and rapid dispatching, as well as a software environment. The program is investigating the placement of integrated modular avionics systems in the wings of the aircraft and intends this to lead to a demonstration program by late 1992.

The IMA program includes activity in the ARINC systems architecture interface (SAI), including proposals for standard software interfaces. SI is

working with the European ASSAC, which is similar to the JIAWG in the U.S. Air Force.

Smiths Industries is working on an automatic flight control system for the EH-101 helicopter, a 30,000-lb helicopter with a 7-hr flight duration. This helicopter was first flown three to four years ago and is currently being prepared to go into production. Key features of the automatic flight control system include a dual duplex architecture with failure survival. Dissimilar hardware and software is used to achieve high integrity. Actuators for stabilization control include series pitch actuators, which act as a trim, moving 10-12% with a parallel actuator with a response of 7 msec end-to-end. Block diagrams of the system were used to illustrate the dual duplex dissimilar processor for auto-stabilization. Flight control computer number one uses the Intel 80286 processor and the Motorola 68000 processor whose outputs are compared and then fed to summers. The summers generate actuator command number one and an output to another comparator, which compares the actuator feedback signal for actuator command number one. Flight control computer number two uses a similar architecture. Both computers use non-synchronous clocks. The software, written and compiled in PASCAL, is 300 to 350,000 bytes. The EH-101 is a maneuverable/unstable airframe that requires auto-stabilization. The demanding environment and requirement for crew attentiveness and mission success dictate full tolerance. The certification process dictates provable integrity. When a fault is detected, it is reconfigured without crew input. SI personnel state that the U.S. military requires a software certification based on an analysis of the code produced, using JSP188. The British CAA has a software certification program similar to that of the U.S. military.

The 80286 provides pitch series B, yaw series B, collective parameter monitor and roll parameter

monitor. The Motorola 68000 provides similar functions for pitch series A, yaw series A, etc. The parallel active processors are Intel and the parallel monitor processors are Motorola. The output of these two are compared and then fed to a switch that selects the output actually fed to the parallel actuator. The second box is similar and provides a total of eight processors for this function.

Smiths Industries is working on a unified flight control for future Harrier-type aircraft. This is an open-loop system that must withstand 25% error in the model. The Avionic Control System Division developed the control laws. Motion feedback is provided to the flight control system, which then provides output commands to the elevator at throttle nozzle and air brake.

The utility management system for the EFA prototype includes the engine, hydraulics, environmental control system (ECS), fuel management system, brakes, and liquid oxygen. One bus control unit controls the utility bus, which is a dual MIL STD-1553B, and interfaces with the avionics utility bus, also a dual MIL STD-1553B bus. The Tornado formerly had the equivalent of 20 to 25 LRUs. SI reduced this to four dedicated LRUs in the EFA. They are investigating using an optical bus. The EFA utility bus is redundant with a cockpit display remote terminal, front computer, right and left fuel computers, and right and left secondary power system computers.

The Long Bow Apache power management system controls the loads on the primary buses but doesn't control the generators.

Flight management systems include utilities management and flight control for rotary aircraft. These represent new thrusts for the Management Systems Division. Flight control systems work includes auto-throttles, air data, para-visual

directors, wing sweep computation, actuators for the auto-throttles, VMS, stores management, data management, air navigation, and flight management. The company uses vibrating cylinder pressure sensors for a digital air data computer. The system has passed EMI tests. SI has developed an enhanced flight management system, including flight planning, navigation, performance, flight prediction, and vertical and lateral guidance for the A300/A310. The company is also working on similar systems for the Navy E6 aircraft designed for submarine communications. The division is using microcircuit engineering for a MIL-STD-1553 chip set. Work is under way in the data bus area, performing bus traffic analysis concerned with merging file data the pilot may want without upsetting the normal data flow sequence. Distributed control modules built into the wing for slat, flap control and landing gear control are being studied.

5.2 Display Systems

Smiths Industries has provided HUDs for the Harrier, Jaguar, Tornado, Hawk, Sea Harrier, and Northrop F-5E. The SI HUDs are shadow-masked CRTs manufactured by Tektronix. A multi-purpose color display (MPCD) has been used for full-color display video maps and video from FLIR sensors. Symbols are generated using a stroke generator.

Work continues on the shadow-masked CRT. Eighty percent of the beam energy is dissipated in the CRT's shadow mask. Their type 2100 is 5 in. x 5 in. and is used on the F-18. The video interface uses NTSC-encoded output. The predicted mean time between failure (MTBF) is greater than 3,500 hours. SI uses a multifunction soft key panel. Work is being done on a 6 in. x 6 in. shadow-masked CRT. The performance loss is proportional to the area, which is 44% greater (25 in.² compared to 36 in.²). The resolution laws for going from 5 in.

to 6 in. is proportional to the width of 20%. SI is experimenting with techniques to regain performance by raising the potential from 25 kV to 28 kV. They are increasing the current from 1.7 mA to 2.0 mA. This reduces the mask loss to 26%. They have developed a 3-D computer model and built samples of the 6-in. display.

Flight deck and cockpit work includes FPDs, including the development of a flat backlight for the LCD. Work is also being done on mission management aids such as the pilots' associate type. SI is working on flight deck warning/diagnostic systems, speech technology with DVI and DVO, and various other MMI aspects. Technologies in development include engine/transmission monitoring. Techniques used for this development include broadband acoustic sensing distilled by a numeral neural network. Computing technologies include parallel processing for displays, integrated modular avionics, networking, fault tolerance, and neural networks enabling technology.

Smiths is working on an ECAM system in which the graphics pages representing the status of the aircraft subsystems display the status on the top half of the page, the command on the bottom left, and the status on the bottom right. An intelligent cockpit warning system with reduced incidence of false alarms is being designed. It will also function to provide isolation of abnormalities and prediction of effects of abnormalities. The design approach involves a network of models that pass among each other values of parameters. The network supervisor produces high-level assessment and provides advice to the pilot via graphics text. The advice is a combination of AI and fuzzy logic, etc. They search for a solution in the problem space. The underlying model is quantitative, and a separate model forms the deductions. For multiple-fault cases, it selects the best response the "best pilot" would make. The goal is to minimize the time between detection of

an abnormality and system failure through the monitoring of trends. It provides advice consistent with operating manuals.

Electronic integrated displays using shadow masks for CRT displays are being developed. These use a holographic combiner to focus the CRT images. Other work in the display area includes a solid-state altimeter using etched microstructures and electrostatics in place of the vibrating cylinder. This allows a much smaller altimeter package than with the vibrating cylinder pressure sensor.

Work is progressing on glare shield displays to provide the pilot with ATC information. An ELS is being designed to eliminate paper from the cockpit. LCD technology is being developed for 1995 certification. SI has identified to date only one American company capable of building the glass for the LCD and has suggested that establishment of second sources within the United States would potentially eliminate dependency on Asian technology. Another SI product is a right-hand glare shield for the EFA that would display angle of attack, ADI, HSI, airspeed in knots, and vertical velocity in ft/min.

5.3 Optical Programs

The optical sensors research currently under way at the Putney plant will be moving to the Basingstoke facility. Areas of investigation center on high-temperature optical thermometry systems derived from the installed thermocouples in the Pegasus engine. These thermocouples will soon be replaced with sensors further upstream in the hot section. The Basingstoke airborne pyrometer system uses optical sensors connected to electrical transducers. The pyrometer is very good at looking at blade temperature. Ways of controlling gas temperature, which is 1,000°C to 1,300°C, should be

investigated. The use of fiber-optic temperature sensors, which allow study of the integrated spectral power versus temperature, are being explored.

The operability of the blackbody fiber-optic thermometer at temperatures ranging from 1,500°C to 2,000°C is being examined. The sensor under investigation has a 2-mm-diameter tip and consists of platinum bonded to sapphire using a 500-mm sapphire rod. SI has developed a proprietary method to attach platinum to the sapphire rod and the sensor has experienced over 500 cycles in a flowing hot gas stream with minimal damage to the tip. The bonded tip is placed into the hot flow and the output goes first to a lens and then to an optical wave guide. The design was initially aimed at the instrumentation. Under study are various materials needed for the protective sheathing around the sapphire rod, which contains the blackbody material on its tip. SI does not believe a thermometer that operates at 2,000°C will be achieved in the near future.

Applications of the optical rotary position sensor include:

- A fiber wire control system that has high certification costs and problems with lightening, EMI, and nuclear events
- Position sensing for flight control propulsion

High precision is required for this type of sensor. Measurements must be absolute with no recalibrations required and must attain a resolution of 0.1% with $\pm 0.5\%$ accuracy. The rotary position sensor uses the wavelength division multiplexed (WDM) system, which has $\pm 40^\circ$ motional displacement.

Future rotary sensory technology will include FBL optoelectronic subsystem elements. High reso-

lution is required and the FBL system must be made more rugged and qualified. SI believes a prototype FBL system will be in an aircraft by 1995.

Work is being done on a new optical sensor concept for aeronautics (NOSCA). This is a joint program with Thomson-CSF, Sextant Avionique, and others. This involves an integrated interferometric measurement system with common multiplexing of fiber-optic sensors suitable for subsequent applications in avionics. Thomson/Sextant is using F.A.S.E. fiber for a pressure sensor and Smiths is using a bow-type fiber for accelerometers. The NOSCA accelerometer separates from the sensors using fringe patterns. The first experiment concerns a quasi-distributed sensor network.

Optical data busing for the utility management system is being considered. The designs being considered have digital signals coming into the avionics data bus from the sensors. A limited set of electronics would provide the signal digitizing capability. The B-777 load management system is being considered as is optical data bussing for the electrical power distribution load management system.

Some of the company's motivation for considering optics is due to the high certification costs and complex issues regarding the wiring interconnects and harnesses in high-EMI environments.

Smiths is also researching the design of optical systems to replace the connector interface on the FADEC. Virtually all the problems that occur with the control can be traced to the interface box. Optical systems would simplify the connector interface.

Smiths Industries proposes to run raw power to the actuators and control the flow of electrical energy to the actuator with optical signals. Work to

use GaAs for the high-temperature electronic capability is under way. The company's design philosophy for constructing the control is to make it sufficiently versatile that it can be treated like a building block set. That is, additional boards required can be added in the future.

Smiths Industries is prepared to demonstrate an optical fuel-gauging system. They have acoustic fuel-gauging systems flying in parallel with the standard capacitance fuel-gauging systems. The fuel management system uses a unique signal bus cross-over technique in which the separate channels from fuel-level sensors enter the box at the connectors, cross over to the next section of electronics, and

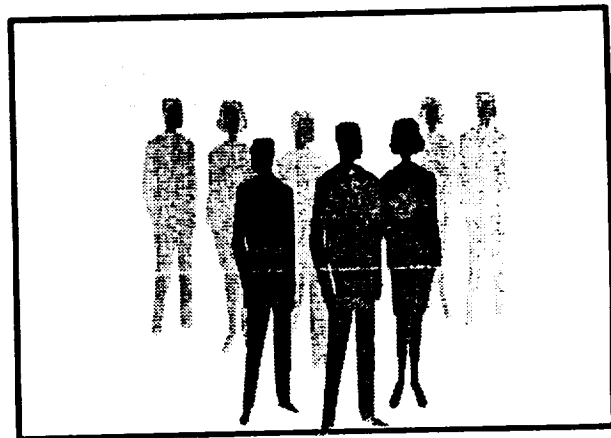
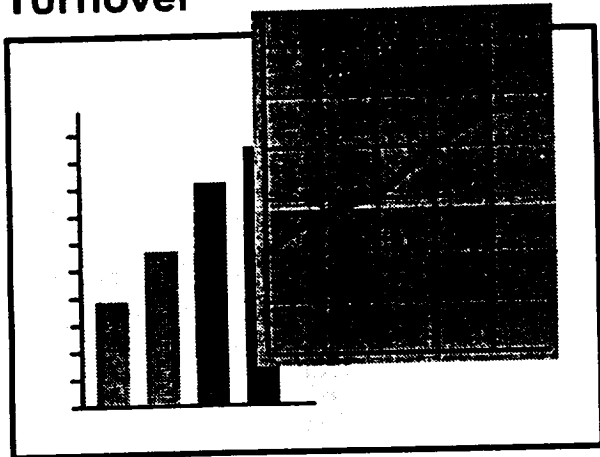
then cross over again as the signal lines exit the components.

There is also ongoing long-term research to develop optical sensing and multiplexing (mux) techniques. The mux technique being pursued is the coherent multiplexing technique, which works on the interferometric principle and requires a single-mode optical data bus. Researchers are looking into developing an optical 629 architecture. The long-term R&D group is also scheduled to conduct optical backplane research.

A brief overview of Smiths Industries corporate composition is provided in Figures A.7-1 to A.7-4.

Smiths Industries

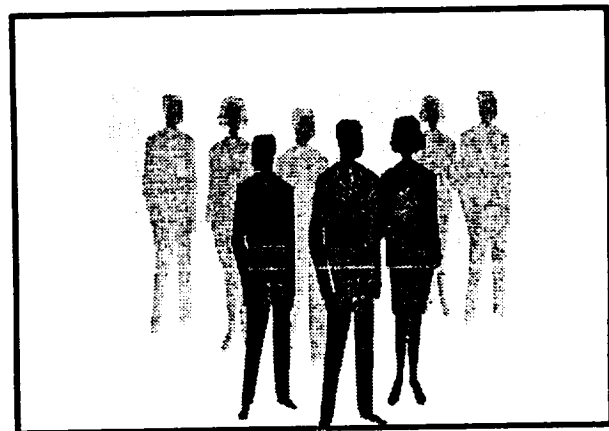
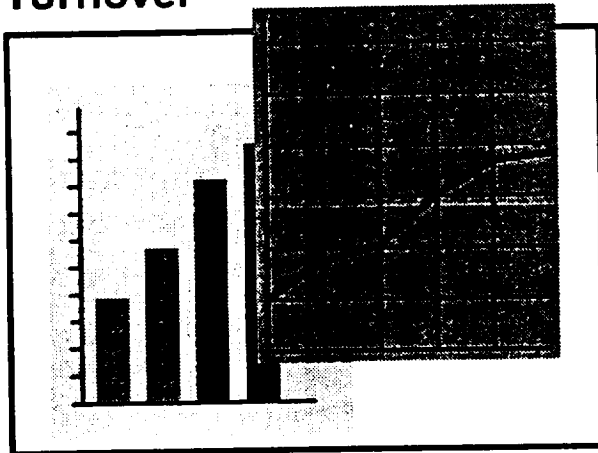
**£675 Million
Turnover**



**13,500 Employees
Worldwide**

Aerospace Group

**£455 Million
Turnover**



**8,500 Employees
Worldwide**

Figure A.7-1. Smiths Industries Corporate Statistics

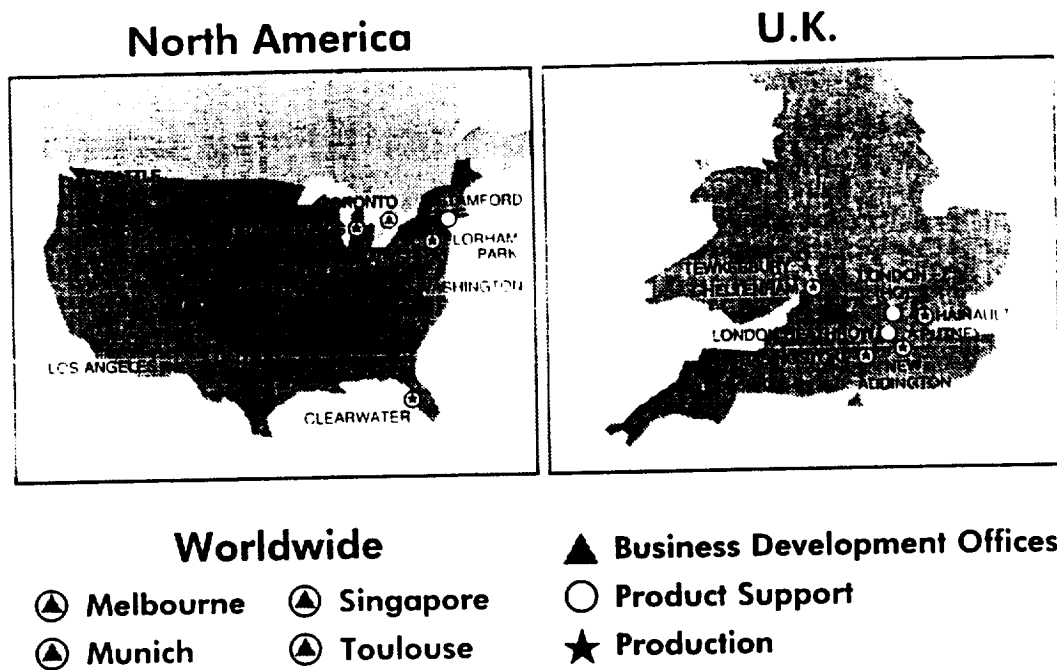


Figure A.7-2. Smiths Industries Worldwide Locations

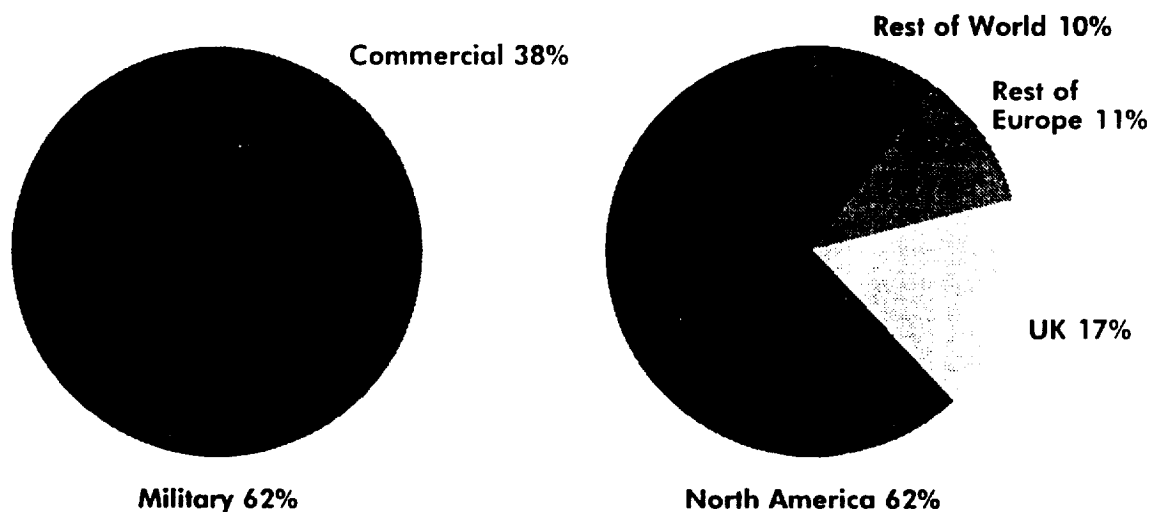


Figure A.7-3. Smiths Industries Worldwide Sales

Product Groups

- Aero-Engine Controls
- Aero-Engine Transducers
- Airborne Monitoring Systems
- Airborne Navigation Systems
- Airframe Systems
- Display Systems
- Flight Control Systems
- Flight Instruments
- Fuel Measurement
- Ground Test Equipment
- Military Upgrade Avionics
- Radar Altimeters
- Reference Systems
- Space Systems
- Stores Management
- Maritime Systems
- Land Navigation Systems

Figure A.7-4. Summary Listing of Smiths Industries Product Groups

APPENDIX A8

SITE REPORTS

*British Aerospace Commercial Aircraft
Sowerby Research Center
FPC 267
PO Box 5, Filton
Bristol BS12 7QW, England
Telephone: (0272) 363136
Telefax: (0272) 364344/362284*

1.0 Date of Visit:

June 26, 1991

2.0 Panel Members:

Daniel Martinec
Robert Baumbick
Cornelius Leondes
Monica Mayton
Joseph Traybar
Joseph Schwind
Cary Spitzer

3.0 Principal Contacts at Facility:

Roger W. Taplin
David Gregory
John Penny
C. R. Davies
P. J. Smith
P. Emerson
Alan Crowther
M. Brown
C. Stace

Chief Systems Engineer
Assistant Chief, Research
Manager, Computer Engineering
Assistant Chief, Systems Engineering

4.0 Facility Overview and Organization

British Aerospace has five commercial plants located throughout the United Kingdom. These locations are:

- Filton, Bristol, England
- Middleton, Manchester, England
- Woodford, Chester, England
- Prestwick, Scotland
- Broughton, Wales

In addition to the companies above, British Aerospace PLC also controls several domestic and international subsidiaries, including: Space Systems, Rover Cars, Construction and Property, British Aerospace Systems and Equipment (BASE), and British Aerospace, Inc. (USA).

British Aerospace (BAe) is a 20% controlling member in Airbus Industrie. In addition, BAe is a contributing member in the design and production of the EFA, the prime contractor to the European Space Agency for the Columbus Polar Platform, and a partner with the Soviet Union on launching a modified space vehicle, HOTOL. Furthermore, BAe Commercial is in its second year of a five-year Control Technology project with GEC, Lucas, and Smiths Industries. British Aerospace (Hawker Sidley), in partnership with Aerospatiale, is world-renowned for the design and production of the Concorde SST. British Aircraft Corporation - Hawker Sidley Aircraft also developed the first glass cockpit and pioneered collaborative (U.K.) industry approaches to achieve technology advances.

British Aerospace PLC has 131,000 employees and sales of \$5.6 billion. British Aerospace Commercial has 21,600 employees and sales of \$761.7 million.

British Aerospace Sowerby Research Center was developed with the intention of looking ahead 5 to 15 years and determining what needs will arise in the avionics systems of the future. Sowerby has 41 human factors engineers with five project areas:

- Visual performance
- Display optimization
- Simulation
- Cognition
- Ergonomics

In addition to human factors research, Sowerby is involved in:

- Advanced information processing
- Optics and laser technology
- Aerodynamics and vulnerability
- Computational physics and special studies
- Materials sciences
- Advance information processing

5.0 Avionics R&D Programs

Some significant avionics research, development, engineering, and manufacturing (RDE&M) projects are:

- Gust load alleviation (GLA)
- Maneuver load alleviation (MLA)
- Control technology
- IMA
- Systems-level communications via ARINC 629
- Reduced maintenance costs (smart components incorporating BIT, improved fault-finding capability, and improved fault-finding resolution)

British Aerospace Commercial Aircraft, Ltd.-Airbus Division is responsible for the design and

production of the wing for the Airbus A300 through A340 aircraft. British Aerospace Commercial Aircraft, Ltd. - Airline Division is responsible for the design and production of the BAe 3100/4100 Series, BAe-ATP, BAe 146, and BAe 125 business jets. Current areas of interest include a 100-plus passenger airplane, to be built by either British Aerospace or Airbus; an ultra-high capacity (700-seat) airplane; and the SST in cooperation with Boeing.

Airbus Division research is centered on airframe technology and manufacturing. The goal of this research is to reduce, drag weight, fuel use, crew training costs, and maintenance costs. Topics being addressed by this research include aerodynamics, structures, systems, and computer engineering.

5.1 Flight Deck Technology Programme

The goal of this program is to develop control interface technology and information interface technology, establish concepts and certification issues, demonstrate control and display information integrity, and establish a pilot-friendly flight deck environment. The overall objective is to achieve cost-effective technology to enhance crew effectiveness and safety. BAe is attempting to identify and develop technology in the laboratory and then implement it into an aircraft simulator for testing and evaluation.

5.2 Miscellaneous Programs

British Aerospace is conducting avionics research and development in several other areas:

Gust Load Alleviation. British Aerospace designed the GLA for the A320. The control actuator rate for this control mode is 300°/sec of control surface movement. GLA is accomplished by providing accumulators out in the wing to

supply power to the outboard spoiler and aileron. Gust sensing is accomplished by using accelerometers located forward of the center of gravity.

Maneuver Load Alleviation. For the A340, MLA is accomplished using the normal control surfaces, damping active yaw with the rudder. A special yaw control actuator is located on the rudder to provide the damping. No flutter suppression control is being studied.

Advanced Flight Deck Designs. Work in advanced flight deck design is also being pursued. The objective is to produce a modular simulator for maximum reconfigurability yet maximum realism. Voice-initiated response is being considered. Smiths Industries designed the voice recognition chip with a bandwidth of 4 kHz. Future work is directed to providing true 3-D capability and use of virtual cockpits (no windows).

Cockpit Optimization. Work is being done in cockpit optimization in terms of human factors. The main thrust is in the psychophysical and cognitive areas. The work in psychophysics is concerned with the relationship between perceived and physical attributes of stimulus (i.e., color of displays, text, etc.). The work in cognition deals with measuring perception by something other than the stimulus to the response (i.e., the pilot's experience).

Data Fusion and Knowledge-Based Systems. Research on data fusion and knowledge-based systems as well as research into advanced information processing with optical processing, AI, pattern recognition, and computer vision architecture is under way. Materials research into the behavior of opto-electronic components in adverse environments is being done.

Optical Data Transmission. Research has also been initiated in the area of optical data transmission with the initial efforts being aimed at identifying problem areas for research.

A brief overview of the British Aerospace corporate structure is presented in Figure A.8-1. A summary of the principal research areas and research skills of Sowerby Research Centre is presented in Figures A.8-2 and A.8-3.

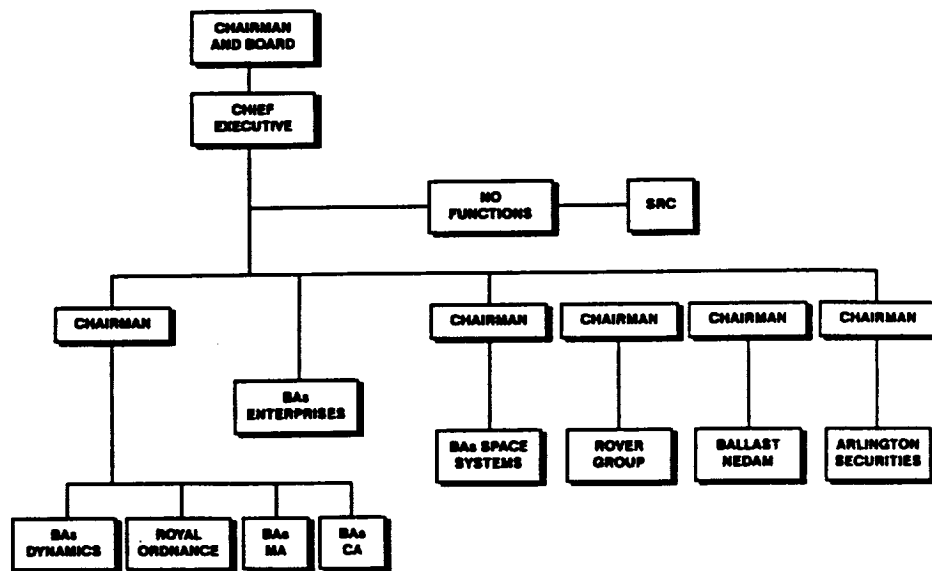


Figure A.8-1. British Aerospace Corporate Structure

ADVANCED INFORMATION PROCESSING

COMPUTER VISION, COMPUTER ARCHITECTURES, NATURAL LANGUAGE, NEURAL NETWORKS,
SENSOR/DATA, FUSION, PATTERN ANALYSIS, ARTIFICIAL INTELLIGENCE

AERODYNAMICS/VULNERABILITY

WIND TUNNEL ANALYSIS, SEMI-EMPIRICAL PREDICTION METHODS, COMPUTATIONAL FLUID
DYNAMICS, STORE CARRIAGE AND RELEASE, PHYSICAL DAMAGE AND RESPONSE, WARHEAD
AND FUSE PERFORMANCE

OPTICS AND LASER TECHNOLOGY

OPTICAL AND LASER SENSORS, OPTICAL IMAGE AND SIGNAL PROCESSING, OPTICAL COMPUTING,
LASER INTERACTIONS, T.E. GAS DISCHARGE LASERS, NON-LINEAR OPTICS, PULSED POWER
TECHNIQUES

HUMAN FACTORS

HUMAN/COMPUTER INTERACTION, VISUAL MODELLING, TRACKING PERFORMANCE, DISPLAY
OPTIMISATION, TELEOPERATION AND CONTROL, TARGET ACQUISITION

MATERIALS RESEARCH

OPTO-ELECTRONICS MATERIALS AND DEVICES, NEW MATERIALS AND PROCESSES, BEHAVIOUR
OF MATERIALS UNDER EXTREME CONDITIONS, NON-DESTRUCTIVE EVALUATION, MATERIALS
STUDIES COORDINATION

COMPUTATIONAL PHYSICS

MATHEMATICAL/COMPUTATIONAL MODELLING, CONTINUUM MECHANICS, NON-LINEAR OPTICAL
PHENOMENA, ELECTROMAGNETIC PHENOMENA, SOFTWARE DEVELOPMENT/EVALUATORS

Figure A.8-2. Sowerby Research Centre Principal Research Areas

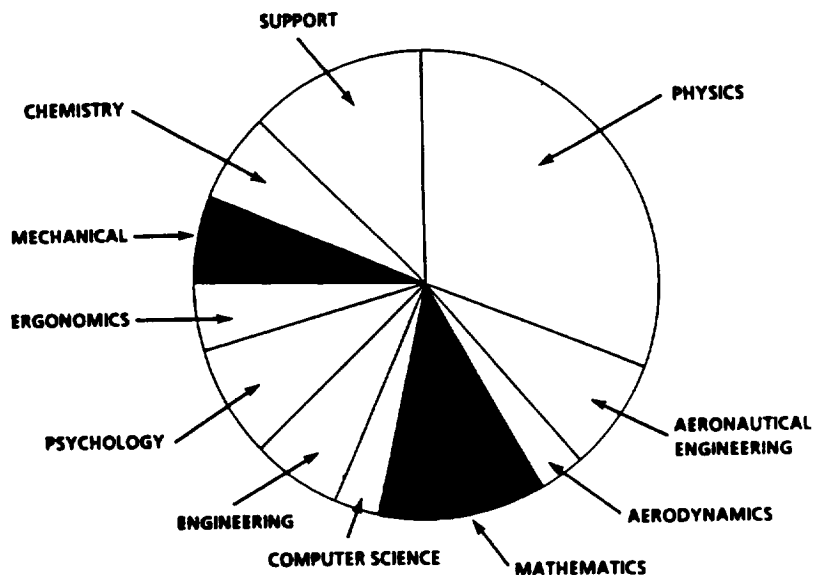


Figure A.8-3. Sowerby Research Centre Skills

<p><i>Teldix GmbH</i> <i>D-6900 Heidelberg</i> <i>Federal Republic of Germany</i> <i>Telephone: (0 6221) 512-231, 242</i> <i>Telefax: (0 6221) 512-305</i></p>
--

1.0 Date of Visit: June 17, 1991

2.0 Panel Members: Ramon DePaula
Alan Angleman

3.0 Principal Contacts at Facility:

Michael Neukirch
Werner Auer
Michael Gartner

4.0 Facility Overview and Organization

Teldix was founded in 1960 as an affiliate of Telefunken and the Bendix Corporation, but it is no longer associated with either of these companies. The Teldix facility in Heidelberg was originally established for aviation equipment production, and Bendix ownership was needed to allow a German-owned company to work in avionics. Teldix GmbH is a member of Bosch Telecom, which includes six other German companies involved in communications, video, and other areas of electronics for both governmental and commercial customers. Approximate total sales are 1.5 billion DM, or \$850 million annually. Although only 20% to 25% of their products have commercial applications, Teldix plans to emphasize this area and double their sales in the next few years to compensate for reduced defense spending by the German government.

Teldix was involved in the production of all German first-generation post-war aircraft. Although they started production of outside designs under license to foreign companies, they soon started their own developmental efforts. Teldix has provided HUDs and missile control systems for Tornado combat aircraft and is participating in the development of the EFA with up to 80 million DM (\$45 million) of support from the German government.

Teldix now comprises five major departments. These are:

- Research and Development
- Marketing
- Production
- Quality Assurance
- Administration

Research and Development comprises one-fourth of Teldix's total staff of 800. These employees are

engaged in space technology, computer technology, equipment, and systems technology. Marketing focuses on land navigation, avionics and marine equipment, space equipment, and industrial technology. The Quality Assurance Department has a staff of 60.

5.0 Avionics R&D Programs

Avionics research, development, engineering, and manufacturing projects include work on:

Computers. Special-purpose computers for navigation of aircraft, ships, and land vehicles, bus systems to STANAG 3838, STANAG 3910 and Ada compilers

Gyroscopic instruments. North-seeking gyros, directional and vertical gyros, and laser gyros

Displays. Combat aircraft HUDs and helicopter navigation and position map displays

Control systems. Servo-control systems and actuation systems for dynamic flight control, including electromechanical high-power actuators for helicopters and aircraft.

5.1 Fiber-Optic Gyros

Since the early 1980s, Teldix has supported research in ring lasers and fiber-optic gyros. Teldix focuses its immediate research and development effort on fiber-optic gyros for applications in the land navigation of tanks and other armored vehicles. Teldix is also interested in the avionic and automotive market.

Teldix uses a design that permits the use of relatively inexpensive fiber because gyro performance is not keyed to specialty (e.g., polarization-

preserving) fiber. The Teldix design also uses asymmetrical windings, which simplifies and reduces the cost of production. The Teldix gyro operates with digital detection.

Fiber-optic gyros offer the potential of reduced costs compared to conventional alternatives.

The use of fiber-optic gyros in combination with the GPS could constitute a very capable land navigation system.

Teldix will have a commercial fiber-optic gyro ready to market by the mid-1990s.

Teldix has developed an experimental single-axis, hand-size, fiber-optic gyro with 200 m of fiber. They have tested this design from -40°C to $+60^{\circ}\text{C}$. It has demonstrated a drift rate of $10^{\circ}/\text{hr}$, which is comparable to operational land navigation gyros. Teldix plans to improve performance in terms of drift rate while expanding the scope of their efforts to include three-axis designs.

6.0 Non-Avionics Areas of Endeavor

Non-avionics areas of endeavor include satellite hardware such as momentum wheels, microwave switches, optical encoders, antenna pointing mechanisms, microstepping motors, and navigation and map display systems for land and sea applications.

APPENDIX B

*INFRASTRUCTURE OF THE
EUROPEAN ORGANIZATIONS*

INFRASTRUCTURE OF THE EUROPEAN ORGANIZATIONS

This appendix provides a cursory overview of the basic infrastructure of the European organizations. More detailed descriptions of fundamental operational characteristics and the logistics of each company or laboratory are provided in Section 3.

B.1 GOVERNMENT, NON-PROFIT, ACADEMIC, AND INDUSTRIAL ORGANIZATION INTER- RELATIONSHIPS

The interrelationships between the governments and private organizations in Europe are virtually the same as in the United States. As in the United States, there is a wide range of types of business relationships in Europe. The following synopses provide basic summaries of the organizations' business relationships.

B.1.1 Airbus Industrie

Airbus Industrie is a European consortium, with the shareholders being Aerospatiale (37.9%), British Aerospace (37.9%), Deutsche Aerospace (20%), and CASA (4.2%). The shareholding companies also perform portions of Airbus' aircraft and avionics manufacturing. Other companies such as Smiths Industries, Sextant Avionique, Deutsche Airbus, and GEC Avionics are subcontractors for the Airbus Consortium.

The shareholders of the Airbus Consortium are not limited in their investments. Aerospatiale, for example, is part of other cooperative European ventures, including Avion De Transport Regional, Eurocopter, Arianespace, Eurosatellite, and Euro-missile. Similarly, subcontractors for Airbus are not

dependent on Airbus for the entirety of their business.

As in the United States, these companies are profit-oriented. They operate in a competitive market and are subject to economic pressures both domestically and internationally. Their customers are both private and government-owned organizations.

B.1.2 Research Labs

The Sowerby Research Center, which is part of British Aerospace, is funded not only by British Aerospace, but also by other private organizations and the government. For example, the Advanced Information Processing Department funding is provided in part by the Ministry of Defense (MOD), the Department of Trade and Industry (DTI), and European initiatives such as ESPRIT. Many of its projects require collaboration with other industries, universities, and research facilities for funding.

ONERA was founded in 1946 as a public scientific and technical establishment, managed according to industrial and commercial practice. It was placed under the authority of the Minister of Defense (equivalent to the U.S. Director of Defense Research and Engineering). In 1984, general management of ONERA was placed under a chairman of the board supported by the High Scientific Committee and a Scientific and Technical Committee. Approximately one-third of the funding is provided by the MOD. Most of the balance comes from negotiated contractual work.

DLR is almost entirely supported by public funding. Its research activities are closely related to government-sponsored research programs. Of particular importance are the programs in the field of aeronautical and space research. DLR cooperates with other domestic and foreign research organi-

zations including ONERA, universities, private companies, and federal and state agencies. Dornier and Messerschmitt-Bölkow-Blohm (MBB) are key companies in DLR's work.

APPENDIX C

BIOGRAPHIES OF PANEL MEMBERS

ELLIS F. HITT

Battelle

EDUCATION

Bachelor of Science, Electrical Engineering, University of Kansas, 1960

Master of Science, Electrical Engineering, Air Force Institute of Technology, 1962

EMPLOYMENT HISTORY

1977 to Present

Battelle Chief Engineer of Battelle's Design Engineering Program contract with USAF Air Logistics Centers and Avionics Engineering Business Development Manager. At Battelle, he is currently leading the development of common avionics modules and common avionics reusable software projects.

1975 to 1977

TRW Systems Chief Engineer for TRW on the Digital Avionics Information System program at the USAF Avionics Laboratory.

1974 to 1975

The Analytic Science Corp Directed flight test of six different Omega navigation systems for USAF/ASD.

1966 to 1974

Battelle Project Manager, Avionics Systems Programs.

1960 to 1965

United States Air Force Entered the US Air Force as an officer in August 1960 and served as an engineering officer/projects manager in navigation, guidance, and control development and test positions in the USAF through 1965.

AFFILIATIONS/LICENSES/ HONORS

Mr. Hitt has authored over 20 papers and 100 technical reports. Member of IEEE and ION.

ROBERT BAUMBICK
NASA Lewis Research Center

EDUCATION

Bachelor of Science, Electrical Engineering, Cleveland State University, 1962

Master of Science, Electrical Engineering, University of Toledo, 1973

CURRENT POSITION

Senior Electronics Research Engineer serving as Program Manager of NASA's Flight-by-Light programs for military and civilian aircraft.

PREVIOUS EXPERIENCE

Analog and digital simulation work on engine control systems. Experimental work on rocket engine propellant feed systems, aircraft engine control systems, supersonic inlet controls research programs and development of engine control components. Research on optical sensor technology for aeronautics applications.

DAN MARTINEC
Aeronautical Radio Inc.

EDUCATION

Bachelor of Science, Electrical Engineering, University of Pittsburgh, 1971

EMPLOYMENT HISTORY

1978 to Present

Aeronautical Radio, Inc. Chairman and Director of Avionics Engineering on the Airlines Electronic Engineering Committee (AEEC); past Secretary and Vice-President of AEEC.

1976 to 1978

ARINC Research (a division of ARINC). Studied the feasibility of avionics integration and prepared the avionics planning baseline for the U.S. Air Force.

***AFFILIATIONS/LICENSES/
HONORS***

Serving on the Board of Governors for the Aeronautical Electronic Systems Society (AESS) of IEEE; Vice-President of Administration of AESS.

CORNELIUS LEONDES
Electrical Engineering Professor

EXPERIENCE

Electrical Engineering Professor Cornelius Leondes now holds the Boeing-Martin Professorship created by Boeing's Endowment for Excellence. Leondes is also Professor Emertius at UCLA. His publications address a wide range of topics, such as flight control systems (commercial and military), industrial systems, and multi-sensor data fusion, and include a series of 38 volumes for Academic Press.

Professor Leondes has offered an impressive range of courses during his distinguished career. He has created and taught short courses for defense and aerospace professionals on topics such as guidance and control for tactical aircraft, missiles, and (smart) armament systems. He has served on blue-ribbon panels for the moon program and the B-1 bomber, and also chaired the NATO advisory group on aerospace research and development.

JOSEPH SCHWIND
Airline Pilots Association

EDUCATION

Bachelor of Science, Aeronautical Engineering, St. Louis University, 1961

Bachelor of Science, Electrical Engineering, St. Louis University, 1965

Numerous technical and administrative courses - George Washington University, Catholic University, University of Kansas and Boeing Aircraft

EMPLOYMENT HISTORY

1974 to Present

Airline Pilots Association, Washington, DC. Deputy Director, Engineering and Air Safety

1974

Piper Aircraft Corporation, Loch Haven, PA. Manager, Avionics Systems

1966 to 1974

Bendix Corporation, Ft. Lauderdale, FL. Manager, Systems Engineering, Bendix Avionics Division

1959 to 1966

McDonnell Aircraft Corporation, St. Louis, MO. Design Engineer

1954 to 1958

U.S. Navy. Flight Engineer, Structures/Hydraulic Mechanic, Radar Operator

**AFFILIATIONS/LICENSES/
HONORS**

FAA - Airline Transport Pilot

FAA - Commercial, Instrument, Multi/Single-Engine Pilot

FAA - Airframe and Power Plant Mechanic

FAA - Designated Engineering Representative (DER) in Systems, Equipment, Structures and Flight Test

MONICA MAYTON

Wright Patterson AFB

EDUCATION

Bachelor of Science, Human Factors Engineering, Wright State University, Dayton, OH
M.S. Human Factors Engineering, Wright State University, Dayton, OH

EMPLOYMENT HISTORY

1989 to Present

Wright Patterson Air Force Base. Specializes in Human Factors issues applying to world-wide aircraft systems under the U.S. Air Force Systems Command at Wright Patterson Air Force Base. Currently head of her division's Human Factors group, Mrs. Mayton has been working to increase the group's efforts involving advanced aircraft cockpit control and display issues.

Prior to 1979

Midwest Systems Research. As contractor for the Flight Dynamics Laboratory at Wright Patterson Air Force Base, Mrs. Mayton worked with advanced experimental fighter cockpit display format and symbology concepts, from monochrome LED moving-map landing plates, to experimental three-dimensional multi-color target identification techniques.

Other civil aviation-oriented work at MSR involved a co-effort between MSR, the FAA Technical Center in Atlantic City, and NASA Ames in San Francisco, California. Mrs. Mayton served on a team of engineers involved in the research, design, test and evaluation of a new experimental primary weather display for the FAA's Mode-S data link system.

JOSEPH J. TRAYBAR
Federal Aviation Administration

EDUCATION

Bachelor of Science, Aeronautical Engineering, St. Louis University
Master of Science, Aeronautical Engineering, Pennsylvania State University
Masters in Management, Embry University

EMPLOYMENT HISTORY

1979 to Present

FAA Technical Center. Research Program Manager for Flying Qualities and Operations Programs. Conducted research in flying qualities/stability and control/flight control systems/all-weather operations and certification/safety assessment of advanced rotorcraft, VTOL, transport airplanes, commuter aircraft, and general aviation vehicles. Technical focus was on conventional aircraft systems as well as the more advanced fly-by-wire and fly-by-light systems.

1959 – 1979

Princeton University. Research Associate/Faculty position in the Aeronautical Engineering Department. Research Program Manager on flying qualities/flight mechanics studies related to rotorcraft, VTOL, STOL, and airplanes. Chief Test Pilot, Flight Mechanics Laboratories.

U.S. Air Force. Flight Commander in a jet, all-weather, night-fighter interceptor squadron; Chief Test Pilot (Maintenance) at the squadron, group, and wing levels; Chief Flight Test/Quality Control Section; Squadron Flying Safety Officer.

**AFFILIATIONS/LICENSES/
HONORS**

Served as consultant to several aerospace aircraft/aircraft companies, research companies and organizations. Chairman, President, Technical Manager, Technical Chairman, Forum Chairman, Workshop Moderator, etc., for numerous professional/technical organizations and societies.

APPENDIX D

ACRONYMS AND ABBREVIATIONS

ACRONYMS AND ABBREVIATIONS

A/C	Aircraft
ACAH	Attitude-Command/Attitude-Hold
ACARS	Aircraft Communications Addressing and Reporting System
ACE	Actuator Control Electronics
ACMS	Aircraft Condition Monitoring System
ADA	Acceleration Detector Assembly
ADD	Airborne Display Division (GEC Avionics)
ADI	Attitude Directional Indicator
ADIRS	Air Data and Inertial Reference System
AFCS	Automatic Flight Control System
AFES	Avionics Flight Evaluation System
AFPG	Automatic Flight Path Guidance
AFSC	Air Force Systems Command
AFTI	Advanced Fighter Tactical Interceptor
AHRS	Attitude and Heading Reference System
AI	Artificial Intelligence
ALPA	Airline Pilots Association
AMLCD	Active Matrix Liquid Crystal Display
APU	Auxiliary Power Unit
ARMS	Aircraft Recording and Monitoring System
ASC	Aircraft Service Center, Lemwerder, Germany
ASD	Aeronautique Spatial Defense (Aerospace & Defense Branch, Sextant Avionique)
ASIC	Application-Specific Integrated Circuit
ATA	Air Transport Association
ATC	Air Traffic Control
ATI	Austin Trumbull Indicator
ATM	Air Traffic Management
ATMOS	Air Traffic Management and Operation Simulator
ATR	Avion de Transport R�gional
ATS	Auto-Throttle System
ATTAS	Advanced Technologies Testing Aircraft System (Germany),
b	Bit
B	Byte
BAe	British Aerospace

BASE	British Aerospace Systems and Equipment
BIT	Built-In Test
C ³ I	Command, Control, Communications, and Intelligence
C	Celsius
C/A	Coarse/Acquisition
C*/C-STAR	Flight Control Law and/or Flying Qualities Criterion
CAA	Commercial Aviation Authority
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CASA	Airbus Industrie Member Country - Spain
CASE	Computer-Assisted Software Engineering
CATMAC	Cooperative Air Traffic Management Concept
CCIP	Continuously Computed Impact Point
CCRP	Continuously Computed Release Point
CDU	Control and Display Unit
CFRP	Carbon Fiber Reinforced Plastics
CGH	Computer Generated Holograms
CMC	Centralized Maintenance Computer
CMS	Centralized Maintenance System; Common Modular Simulator
COMPAS	Computer-Oriented Metering, Planning, and Advisory System Project
CP	Combined Protocol
CRT	Cathode Ray Tube
CSI	Composants et System es Industriels (Components & Industrial Systems Branch, Control Technology Programme/Integrated Modular Avionics)
DA	Deutsche Airbus GmbH Company
DAR	Digital ACMS Recorder
DARPA	Defense Advanced Research Projects Agency
DAS	DME-based Azimuth System
DCP	Digital Coding Panel
deg	Degree
DFBW	Digital Fly-by-Wire
DFDRS	Digital Flight Data Recording System
DLR	Deutsche Forschungs-und Versuchsanstalt fur Luft-und Raumfahrt (German Aerospace Research Establishment)
DM	Deutsche Marks
DME	Distance Measuring Equipment
DMU	Data Management Unit

DoD	Department of Defense
DTI	Department of Trade and Industry
DVI	Direct Voice Input
DVO	Direct Voice Output
ECAM	Electronic Centralized Aircraft Monitoring
ECM	Engine Condition Monitoring
ECS	Environmental Control System
EEC	European Economic Community
EEPROM	Electrically Erasable Programmable Read Only Memory
EFIS	Electronic Flight Instrument System
EFMS	Experimental Flight Management System
EGT	Exhaust Gas Temperature
EHRS	Abbreviation for "Flight-Hours" on Engine Report 01
ELAC	Elevator and Aileron Computer
ELS	Electronic Library System
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMU	European Monetary Unit
EO	Electro-Optic
EPOPEE	Etude Prospective d'Organisation d'un Poste d'Equipage Ergonomique (Investigation of the Ergonomics of the Piloting Station-Aerospatiale)
EPR	Engine Pressure Ratio
ESN	Engine Serial Number
FAA	Federal Aviation Administration
FAC	Flight Augmentation Computer
FADEC	Full-Authority Digital Engine Control
FANSTIC	Future ATC, New System and Technology Impact on the Cockpit (Aerospatiale term)
FBL	Fly-By-Light
FBW	Fly-By-Wire
FCSD	Flight Control Systems Division (of Sextant Avionique)
FDDI	Fiber-Distributed Data Interchange
FDIU	Flight Data Information Unit
FDR	Flight Data Recorder
FF	Fuel Flow
FFRATS	Full Flight Regime Auto-Throttle System
FLA	Future Large Aircraft
FLIR	Forward-Looking Infrared Radar
FMC	Flight Management Computer
FMS	Flight Management System

FOCSI	Fiber Optics Control Systems Integration
FOG	Fiber-Optic Gyroscope
FOV	Field Of View
FPCS	Flight Path Control System
FPD	Flat Panel Display
FPI	Flat Panel Instruments
FQS	Flying Qualities Simulator
ft	Feet
GaAs	Gallium Arsenide
GCAS	Ground (or Terrain) Collision and Avoidance System
GE	General Electric
GLA	Gust Load Alleviation
GPS	Global Positioning System
GSE	Ground Support Equipment
HID	Helmet Integrated Display
HIPPS	Holographic Interconnects for Parallel Processing Systems
HLD	Head-Level Display
HLPF	Hydraulics Laboratory and Production Facility
HMD	Helmet-Mounted Display
HMS	Helmet-Mounted Sight
HOL	Higher Order Language
HOTAS	Hands-On Throttle And Stick
hr	Hour(s)
HSI	Horizontal Situation Indicator
HUD	Head-Up Display
HUDWAC	Head-Up Display/Weapon-Aiming Computer
HUDWAS	Head-Up Display/Weapon-Aiming System
Hz	Hertz
IAI	Israel Aircraft Industries
IBU	Independent Back-Up
ICDU	Intelligent Control Display Unit
IFG	Institute for Flight Guidance (of DLR)
IFOV	Instantaneous Field of View
IMA	Integrated Modular Avionics
INMARSAT	International Marine Satellite
INS	Inertial Navigation System
IR	Infrared
IR&D	Internal Research and Development
IRS	Inertial Reference System

J	Joule(s)
JIAWG	Joint International Avionics Working Group
kV	Kilovolt(s)
LANTIRN	Low-Altitude Night Targeting InfraRed Navigation
lb	Pound(s)
LCD	Liquid Crystal Display
LCOS	Lead Computing Optical Sight
LECOS	Light Electronic Control System
LED	Light-Emitting Diode
LED-EICAS	Light-Emitting Diode - Engine Instrument Crew Alert System
LH	Light Helicopter
LLTV	Low-Light Television
LRU	Line Replaceable Unit
m	Meter(s)
MB	Megabyte(s)
MBB	Messerschmitt-Bolkow-Blohm
MCDU	Multi-Purpose Control Display Unit
MDDU	Multi-Purpose Disk Drive Unit
MFD	Multi-Function Display
mHz	Millihertz
mi	Mile
MLA	Maneuver Load Alleviation
mm	Millimeter
MMI	Man-Machine Interface
MOA	Memorandum of Agreement
MOD	Ministry Of Defense
MOI	Ministry Of Industry
MOSY	Modular Strap-Down System
ms	Millisecond
MSE	Main Engine Start
MSR	Midwest Systems Research
MTBF	Mean Time Between Failure
MU	Management Unit
mux	Multiplex
NASA	National Aeronautics and Space Administration
NASP	National Aerospace Plane
NBC	Nuclear, Biological, Chemical
ND	Navigation Display

NFI	No Further Information
NVG	Night Vision Goggle
OCPM	Optically Connected Parallel Machines
ODT	Optical Data Transmission
ONERA	Office National D'Etudes et de Recherches Aerospatiale (Toulouse, France)
PC	Personal Computer
PCU	Power Control Unit
PFC	Primary Flight Computer
PHARE	Program for Harmonized Air Traffic Management Research in Eurocontrol
POC	Point Of Contact
psi	Per Square Inch
PSI	Permanent Standby Instrument
PSV	Permanent Standby Visual System
QAR	Quick Access Recorder
RAF	Royal Air Force
RCAH	Rate-Command/Attitude-Hold
R&D	Research and Development
RD&E	Research, Development, and Engineering
RIAS	Radar Impulsion Antenna Synthetique
RNZAF	Royal New Zealand Air Force
RT	Room Temperature
RWR	Radar Warning Receiver
SAR	Smart ACMS Recorder
sec	Second(s)
SEC	Spoiler and Elevator Computer
SECU	Spoilers Electronic Control Unit
SHUD	Smart Head-Up Display
SI	Smiths Industries
SID	Society for Information Display
sq ft	Square Foot
SRAM	Static Random Access Memory
SST	Supersonic Transport
STOL	Short Takeoff and Landing
SVA	Societe Vendomoise d'Avionique
TARA	Tactical Routing Algorithm
TARMAC	Taxi and Ramp Management and Control

TCAS	Traffic Collision and Avoidance System
TFOV	Total Field Of View
TRIAS	Fast Data Processing Systolic Architecture Electro-Optic Computer
TSRL	Technology and Systems Research Laboratory (GEC Avionics)
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
V	Volt(s)
VLSI	Very-Large-Scale Integration
VME	Versatile Multiplex Europa
VMS	Vehicle Management System
VTOL	Vertical Takeoff and Landing
W	Watt(s)
WDM	Wavelength Division Multiplexed
WPAFB	Wright Patterson Air Force Base
yr	Year(s)
μm	Micron(s)
μs	Microsecond(s)
°	Degree(s)

APPENDIX E

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REFERENCES

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